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# GENERAL AVIATION (FAR 23) COCKPIT STANDARDIZATION ANALYSIS

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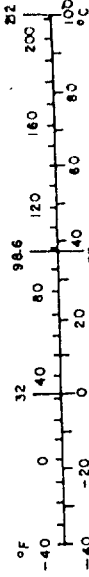
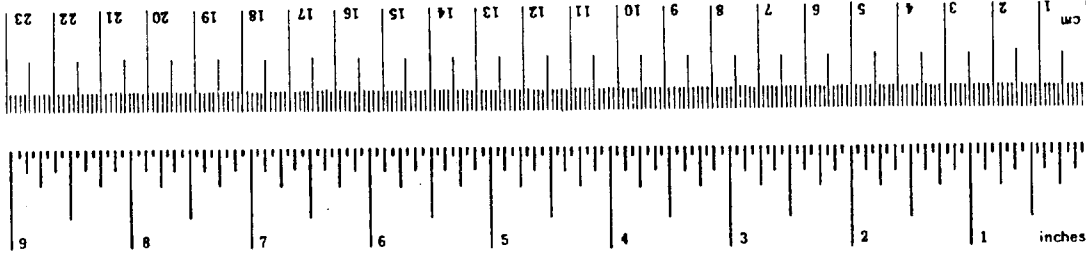
# METRIC CONVERSION FACTORS

## Approximate Conversions to Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
in	inches	2.5	centimeters	cm
ft	feet	30	centimeters	cm
yd	yards	0.9	meters	m
mi	miles	1.6	kilometers	km
<b>AREA</b>				
in <sup>2</sup>	square inches	6.5	square centimeters	cm <sup>2</sup>
ft <sup>2</sup>	square feet	0.09	square meters	m <sup>2</sup>
yd <sup>2</sup>	square yards	0.8	square meters	m <sup>2</sup>
mi <sup>2</sup>	square miles	2.6	square kilometers	km <sup>2</sup>
	acres	0.4	hectares	ha
<b>MASS (weight)</b>				
oz	ounces	28	grams	g
lb	pounds	0.45	kilograms	kg
	short tons (2000 lb)	0.9	tonnes	t
<b>VOLUME</b>				
ts	teaspoons	5	milliliters	ml
Tbsp	tablespoons	15	milliliters	ml
fl oz	fluid ounces	30	milliliters	ml
c	cups	0.24	liters	l
pt	pints	0.47	liters	l
qt	quarts	0.95	liters	l
gal	gallons	3.8	liters	l
ft <sup>3</sup>	cubic feet	0.03	cubic meters	m <sup>3</sup>
yd <sup>3</sup>	cubic yards	0.76	cubic meters	m <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°F	Fahrenheit temperature	5/9 (after subtracting 32)	Celsius temperature	°C

## Approximate Conversions from Metric Measures

Symbol	When You Know	Multiply by	To Find	Symbol
<b>LENGTH</b>				
mm	millimeters	0.04	inches	in
cm	centimeters	0.4	inches	in
m	meters	3.3	feet	ft
m	meters	1.1	yards	yd
km	kilometers	0.6	miles	mi
<b>AREA</b>				
cm <sup>2</sup>	square centimeters	0.16	square inches	in <sup>2</sup>
m <sup>2</sup>	square meters	1.2	square yards	yd <sup>2</sup>
km <sup>2</sup>	square kilometers	0.4	square miles	mi <sup>2</sup>
ha	hectares (10,000 m <sup>2</sup> )	2.5	acres	
<b>MASS (weight)</b>				
g	grams	0.035	ounces	oz
kg	kilograms	2.2	pounds	lb
t	tonnes (1000 kg)	1.1	short tons	
<b>VOLUME</b>				
ml	milliliters	0.03	fluid ounces	fl oz
l	liters	2.1	pints	pt
l	liters	1.06	quarts	qt
l	liters	0.26	gallons	gal
m <sup>3</sup>	cubic meters	35	cubic feet	ft <sup>3</sup>
m <sup>3</sup>	cubic meters	1.3	cubic yards	yd <sup>3</sup>
<b>TEMPERATURE (exact)</b>				
°C	Celsius temperature	9/5 (then add 32)	Fahrenheit temperature	°F



1 in. = 2.54 exact in. For other exact conversions and more detailed tables, see NBS Misc. Publ. 286, *Units of Measure*, Price \$2.25, SO Catalog No. C13.10-286.

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16. Abstract Cockpit design features amenable to standardization in small general aviation aircraft were studied with the goal of increasing safety. A list of 101 cockpit design features was presented to 82 experienced pilots who indicated where they believed increased standardization was warranted. Features cited by half or more of the pilots were studied further and reduced to nine design areas considered to warrant near-term action. Selection of these areas was based on analysis of accident reports and practicality considerations in addition to pilot comments. Three of the design areas relate to the cockpit functions of housing and protecting the pilot (improved body restraint system, more positive action and positive latching of adjustable pilot seats, and door latching with a visible locked state). The remaining six areas relate to the other major cockpit function of providing the man-machine interface required to operate the aircraft (fuel management system, powerplant controls, flight instruments, powerplant instruments, instrument lighting, and electrical circuit breakers). Separate sections of the report summarize the data assembled to justify the recommendation for standardization actions in each of the nine areas.					
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## EXECUTIVE SUMMARY

The continuing high rate of serious accidents in general aviation, with the majority attributed to pilot error, has led the Federal Aviation Administration (FAA) to conduct a research effort that may lead to improvement in the Federal Aviation Regulations (FAR) Part 23 standards for cockpit design. While it is recognized that the lack of cockpit standardization has not been listed as a cause of accidents, increased standardization of cockpit systems can reduce cockpit workload, reduce the potential for habit interference when transitioning to another type aircraft, and provide for application of the best and most error-resistant designs. For example, a uniform grouping of basic flight instruments has long been advocated and, to a large extent, has become standard in current general aviation aircraft. Rules and regulations do not require such a standard arrangement, and in other design areas simplification and standardization are even less advanced.

With time, standards of good engineering practice have evolved for cockpit systems and have been incorporated in federal regulations, industry design guidance documents, and other aircraft standards such as military specifications (MILSPEC). The increasing complexity of navigation and communication equipment and the trend toward more complete instrumentation in small aircraft make it desirable to examine the present state of cockpit standardization to determine if stronger requirements and guidance applicable specifically to single and light twin-engine aircraft are appropriate now.

The method followed in this study was to construct a list of cockpit systems and features, ask experienced pilots if any of these areas or features now required increased standardization, and assemble accident/incident data and information on the desirability and practicality of regulatory action in the most critical areas. In addition, contacts with members of the General Aviation Manufacturers Association (GAMA), including visits to major production plants, provided information on the current status of cockpit designs and standardization actions planned by the industry.

The product of this effort is a set of recommendations for cockpit standardization actions. Whether the FAR 23 airworthiness standards should be modified or whether greater standardization should be encouraged in other ways is a question for other government offices and elements of the general aviation industry. This research and development task is concerned primarily with identifying the areas of cockpit design that can reasonably be standardized, and developing the justifications to support the recommendations.

To better house and protect the pilot and other occupants, the following areas of cockpit design are recommended for industry-wide standardization through changes in Federal Airworthiness Standards or other design guidance documents, as appropriate.

1. All aircraft should have a convenient and safe body restraint system for reduction of injuries.

2. Adjustable pilot seats must be designed to preclude inadvertent slippage which could result in loss of control of the aircraft.
3. Door latching mechanisms and latching status indications should be more standard and more positive in action.

To increase the safety of flight, the following areas of cockpit design, relating to the man-machine interface, are proposed for standardization.

1. Fuel management systems should be standardized as proposed by previous studies and recommendations by GAMA. Additionally, the fuel tank selector should be accessible to both pilots in a side-by-side, dual-control aircraft.
2. Powerplant controls should conform to the standard plan of arrangement, actuation, and coding proposed by GAMA.
3. Basic flight instruments should be arranged in the widely accepted "T" pattern for all general aviation aircraft in which sufficient space is available.
4. Powerplant instruments should conform to a standard arrangement.
5. Instrument lighting should be required for all aircraft approved for either training or night flight. The present FAR 23 exclusion of a cabin dome light as an instrument light should also exclude a single floodlight mounted behind the pilot.
6. For electrical protection, circuit breakers should be used wherever feasible, and should have a readily visible tripped state. They should be grouped and located to provide maximum accessibility to the pilot. Means should be provided to indicate immediate, accurate identification.

These nine areas of cockpit design, listed above, have clear safety implications and are amenable to near-term regulatory action. Other areas such as external cockpit visibility, arrangement, dials, and tuning heads of navigation and communication systems, pilot alerting and cockpit warning systems, and flap position indicators and actuation mechanisms are candidate design areas for study. There was substantial indication of standardization need in each of these areas in the pilot survey, and inspection of current production aircraft confirmed a low degree of standardization.

The data collected in the study indicate the need for regulatory standardization in many areas of cockpit design. FAR 23 and other documents relating to cockpit characteristics should be under continuing study and review. General aviation aircraft are not necessarily becoming larger or more complex in basic structure, but in the cockpit it is undeniable that instruments, controls, avionics, and warning indicators have proliferated to make the panel, overhead, and side areas more crowded as well as more demanding of pilot attention. Earlier cockpits had fewer elements; therefore, it was not so important that each follow a standard pattern of design and arrangement. More standardization is required today, and still more will be essential in the future.

## PURPOSE

The purpose of this effort was to determine those characteristics of general aviation cockpit design that may reasonably be standardized to reduce the potential for pilot errors, accidents, and incidents.

This report recommends nine near-term regulatory and/or design practice actions to achieve improved standardization and cockpit design features. These improvements may be effected through changes in the Federal Aviation Regulations (FAR) Part 23 (reference 1), Advisory Circulars (AC), design handbooks, or other guidance documents.

## BACKGROUND

For many years, airworthiness standards have been incorporated in FAR's, and aircraft designs have evolved in compliance with a body of technical guidance summarized in Civil Air Manuals (CAM), AC's, Department of Defense (DOD) Military Specifications (MILSPEC's), recommended design practices, and industry agreements. Members of the general aviation community, manufacturers, training schools, pilot organizations, publications, avionics and accessory suppliers, and many others, periodically make recommendations to the Federal Aviation Administration (FAA) and other authorities for revisions in regulations or recommended design practices. The role of the FAA has been to compile accident and utilization data, to use these data to determine the needs for regulatory actions, and to recommend good design practices where a safety issue exists. Also, the FAA requires tests to verify the safety aspects of various aircraft features, systems, and maintenance practices.

Many of the standards and recommendations relate to cockpit systems. This study is limited to this aspect of aircraft design. The cockpit figures prominently in any safety analysis because it is the one aircraft area that must meet the requirements of flight and concurrently provide for the requirements of the human occupants. Thus, the cockpit has a dual role, it provides the interface of displays and controls required to fly the aircraft, and it also houses, shelters, and protects the pilot.

A review of the needs for standardization of the control interface function is appropriate because cockpit displays are becoming increasingly complex and diverse, and there is still no uniform arrangement and coding of controls. The design of the cockpit must meet the general requirement that the pilot perform all his/her duties and operate all the necessary controls in a safe manner within his/her known perceptual, reach, and strength limitations. It is generally accepted that it is not enough for the FAR's to delineate minimum design practices which insure that the pilot can see, read, interpret, reach, operate, etc. Uniform use of shape, color, operating feedback, and other coding and uniform arrangement of items is a safety goal because the pilot may go from one aircraft to another and may practice only rarely those skills that are essential in severe weather or other extreme flight conditions.

Providing for the second requirement, housing and sheltering the crew, the cockpit protects the pilot from the external environment, provides shelter from wind, precipitation, cold, noxious gases, and also gives the pilot a measure of protection from the forces operating in accidents or other unusual situations. FAR's cover all these shelter and protection aspects, and they are particularly appropriate for study with respect to crash survivability because of progress made in that area in recent years. There is widespread lack of standardization in cockpit protective features such as seats, body restraints, panel delethallization, exit doors, and door latching mechanisms. All of these have been considered in this study.

#### REQUIREMENTS FOR STANDARDIZATION.

This emphasis on increased standardization of both the control interface and the cockpit protective features is a continuation of the longstanding effort to increase safety in general aviation. An instance of public recognition of the priority of this area occurred early in the history of the FAA in the Bureau of Research and Development Requirement Statement ABI-1, "Uniform General Aviation Cockpit," April 18, 1961 (reference 2), which recommended "Reduction of cockpit workload by the development of a uniform grouping of instruments, navigation and communication equipment and controls, landing gear, flaps, engine and other controls, in general aviation aircraft capable of instrument flight, with emphasis on single-engine aircraft." This statement clearly set goals for the FAA of increasing standardization, by "uniform grouping," and increasing safety with "reduction of cockpit workload."

The National Transportation Safety Board (NTSB) also has called for action to reduce pilot error accidents in general aviation through elimination of unsafe design features. The report, "Aircraft Design-Induced Pilot Error," February 1967 (reference 3), identified lack of standardization as a major cause of accidents.

This subject was also included in the Department of Transportation (DOT) "Report of the Secretary's Task Force on the FAA Safety Mission," April 1975 (reference 4). Recommendation number 10 in that report reads: "FAA must undertake a major safety research program to assure that future aircraft designs make optimum use of crew capabilities, and to ensure that future systems are designed around reasonable criteria for human error."

At the FAA Aeronautical Center, Oklahoma City, Oklahoma, a project report "Cockpit Standards for FAR 23 Airplanes," dated February 1976, recommended: that the FAA work with the aircraft manufacturers to develop improved cockpit design standards, that minimum standards jointly developed by the FAA and the manufacturers be incorporated in FAR 23, and that other design standards be published as recommended design practice, such as Aerospace Recommended Practices (ARP) or Aerospace Information Reports (AIR). The project continued the work of the Society of Automotive Engineers (SAE) Committee on cockpit standards (SAE A-23) who had circulated proposed standards for the location and actuation of aircraft cockpit controls for general aviation aircraft, but that committee was terminated by the SAE before the final standards were drafted. The General Aviation Manufacturers Association appointed working

groups to continue development of proposed revisions to FAR 23 standards on cockpit controls, including fuel valve selectors. These actions indicate that the present minimal standardization in general aviation cockpit design and the continued production of general aviation aircraft with cockpit features poorly engineered for human use are recognized safety problems. Despite this recognition, there is considerable difference of opinion of the desirability of making broad changes in the FAR's. Some think it better to revise the law only where the safety problem is very clear, and encourage standardization by making recommendations that allow for the wide variation in general aviation aircraft cost and complexity of design.

#### MEANS OF ACHIEVING STANDARDIZATION.

There are several methods available to the aviation community to communicate design guidance and recommended practices.

When the intended means of increasing standardization is a change in federal regulations with the force of law, the formal procedure begins with publication of a Notice of Proposed Rulemaking (NPRM) preceded occasionally by an Advance Notice (ANPRM). A period of time is stipulated for comments and responses from interested organizations representing pilots, aircraft manufacturers, avionics suppliers, and other groups and individuals. On occasion, no objections or suggested revision to the proposed rule are included in the comments, and favorable reactions are predominant. In such a case, the proposal would be accepted as adequate and timely, and would become a revision to the FAR. In other instances, the responses and comments on an NPRM may be more variable and may indicate that the regulatory action contemplated is not acceptable to one or another segment of the general aviation community. This consultation process may result in modification of the proposed rule and resubmission to the community for comment. Alternatively, the rule may be modified to comply with suggested changes, or its implementation may be delayed until more information or test data is accumulated, or the rule may be withdrawn from consideration as untimely or unsatisfactory. In a few instances, an NPRM has been withdrawn after consultation, but the ultimate result in the aviation community has been substantial compliance anyway with all or part of the rule. An example of this outcome is found in NPRM 73-1 requiring the installation and use by the pilot of upper torso restraints. The proposed rule was partially adopted, as will be discussed later, but the mass-produced general aviation aircraft examined recently have been equipped with this safety aid.

Another route to increased standardization is the voluntary actions of GAMA in adopting industry standards. In some instances, voluntary agreements to standardize the use of well designed systems may follow the guidelines set forth by an engineering group such as a committee of the SAE, which has a history of promoting standardization and improved design practice. Given a study or report concluding that standardization is practical and desirable in an area such as the content and format of aircraft owner's manuals or the design of aircraft fuel management systems, GAMA may appoint an ad hoc committee of engineering and production experts who may then draft a proposal for review by the general aviation community and the FAA. Roughly paralleling the

procedure followed by the FAA in processing an NPRM, the GAMA standardization proposal may be adopted as drafted, delayed, or modified to incorporate changes. In cases directly involving safety, such as the fuel management standardization proposal, GAMA may elect to suggest to the FAA that the industry agreement be incorporated in the FAR's, thus assuring that all elements of the industry will comply. In other cases, the GAMA agreement may be entirely voluntary with the provision for alternate designs in the case of special purpose or unconventional aircraft.

In addition to the FAR change and GAMA advisory, there are various other means of promoting standardization in general aviation. These include National Airworthiness Standards (NAS), Technical Standard Order (TSO) Authorizations, Airworthiness Directives (AD), Advisory Circulars (AC), the aforementioned SAE products, ARP and AIR, and Aeronautical Standards (AS). As a rule, the SAE documents bear a label advising that their use is voluntary. Design practices recommended by SAE may become industry standards, and on occasion some or all elements of an SAE ARP or AS may be incorporated in a FAR.

#### SAFETY PRINCIPLES RELATED TO STANDARDIZATION.

The relationship between aircraft standardization and flight safety is not one of simple cause and effect and should in no way suggest that aircraft certificated under present rules are deficient in safety, or that increased standardization is itself a panacea. Instead, the safety significance of standardization should be assessed in relation to two principles of accident causation and description.

First, it is widely agreed that most accidents result from a combination of circumstances, not entirely from pilot error, aircraft defect, or environmental stress. Most often, the fully illuminated accident is the end result of a pilot-aircraft-environment causal chain. Recognition of this causal chain implies, however, that the typical accident can be averted by an improvement in any part of the sequence. Increased pilot proficiency, greater safety margins in the aircraft, or less adverse weather might, in a given case, break the chain.

A typical accident causal chain might start with a pilot who is under time pressure and therefore abbreviates flight planning. A correctable defect in the aircraft, such as improper distribution of load causing inadequate stability, may be missed by the hurried pilot. Completing the causal chain may be an unexpected deterioration in the weather forcing the pilot to fly in an unfavorable environment. This sequence might result in an accident, given a particular proficiency level for the pilot, a particular set of aircraft dynamics, and specific environmental stresses. A more proficient pilot might have controlled the unstable aircraft despite the weather, while for an aircraft with greater safety margins, even so minor an item as a better placard on load distribution could have helped the less proficient pilot to complete the flight successfully in the severe environment. And finally, with improvement in the weather, the pilot and aircraft combination might have succeeded. Hence, improvement in safety can follow from improvement in the pilot factor, the aircraft factor, or the environment. All are significant, and hence capable of improvement, although each alone is not necessarily and inherently unsafe.

The second principle relating to aircraft accidents is that investigation does not usually yield the full description of the causal chain. It is not possible to state the exact percentage of accidents and therefore the potential extent of safety improvement to be sought, attributable to pilot factors, aircraft factors, or environment. Many accidents result in destruction of clues to causation. Even full preservation of pilot and damaged aircraft does not insure that the specific sequence of cause and effect, secondary cause resulting from that initial effect, and consequent secondary effect, and final culmination can be reconstructed. Perhaps a personal problem caused the time stress effect on the pilot at the outset. This may not appear in even a very careful investigation. Perhaps the critical cause of the defect in flight planning was the sort of subtle factor mentioned previously, a poorly placed placard. In such a case, it is possible that the pilot himself would not be aware of the operative "aircraft" factor. Finally, the weather or other environmental stresses are seldom capable of exact reconstruction from records available after an accident. The wind, windshear, and turbulence conditions that affected the airplane may not have been recordable at any reasonably close weather station. The investigation cannot then, detail the aerodynamic forces that actually impinged on the aircraft.

These principles of accident causation and description suggest that increased cockpit standardization can be justified if it can be demonstrated that the lack of standardization or the use of designs that are known to be inferior is a contributing cause of accidents. It is not necessary to prove that the particular instance of lack of standardization was the sole or even the culminating cause of the accident. Total system safety would be advanced if increased cockpit standardization reduced the probability that some level of pilot factors would interact with aircraft factors to sustain an accident causal chain. Similarly, it will never be established statistically that any given number of injuries would have been prevented if all cockpits had been equipped with some particular protective feature. This is because, in the real world, it is not sensible to conduct a comparative experiment with real pilots. We do not equip half the fleet with a protective feature, deny that feature to the other half, and compare the number of injuries. Instead, protective features such as body restraints are introduced in variable forms over a period of time. We may be able to infer from individual accident analyses, and from controlled experiments with synthetic accidents, that a substantial safety advantage is achieved by use of the protective system in question, but we cannot actually count lives saved or accidents and injuries prevented. A postulation that safety requires a specific standardization action should never be an absolute statement. Knowledge accrued from experience with different usages in aircraft other than those covered by FAR 23, knowledge from various types of surveys and experiments that do not exactly duplicate the aircraft operational environment, and assumptions based on the logic of causal sequences that are produced by accident analysis should all play a part.

Underlying this study, then, is recognition that the cause influencing the pilot leads to an effect, that this effect may become a cause in the pilot-aircraft interaction, and that many accidents result from a further linkage of that interaction with environmental stress. Since this is the true genesis of most accidents, there are several possible approaches to increased flight

safety. Very important among these approaches will always be the standards of pilot training and proficiency. But better trained and more current pilots are a complement to and not a replacement for improvement in the aircraft factor.

This study attempts to break the pilot-aircraft-environment causal chain at the point that the pilot effect is active in the cockpit. Examination of the stages of pilot-aircraft interaction in the cockpit may suggest a rational approach. Figure 1 illustrates a typical human factors loop of pilot information processing.

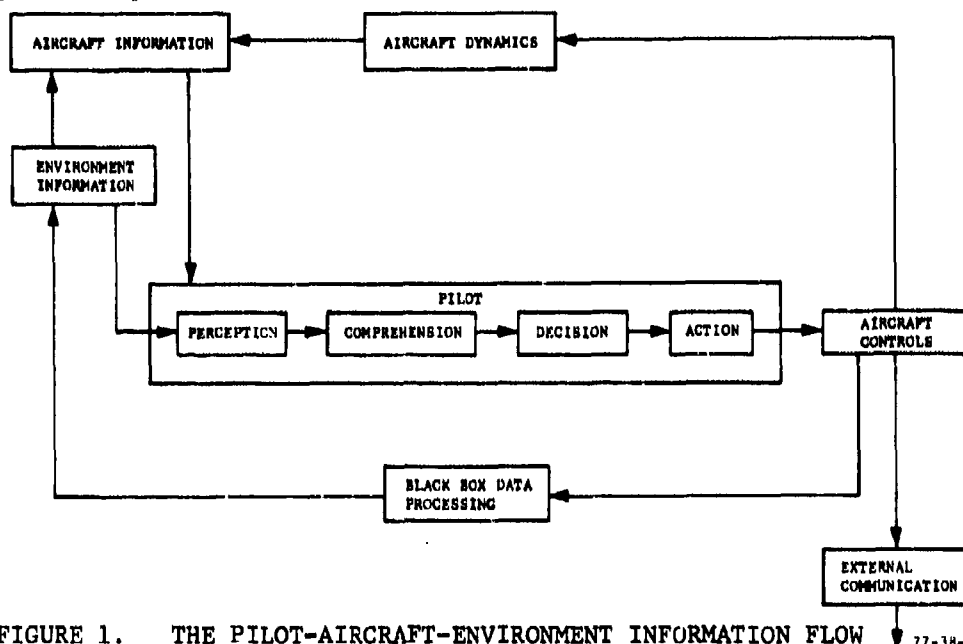


FIGURE 1. THE PILOT-AIRCRAFT-ENVIRONMENT INFORMATION FLOW

77-38-1

The pilot is engaged in the perception of information about his/her aircraft state, dynamics, and the environment. In order to take appropriate corrective action he/she must perceive and correctly comprehend a danger signal among less significant aircraft and environment information. The pilot may not sense the signal if it is not part of his/her audio or video field of recognition, or if it is otherwise blocked. Or he/she may perceive the signal but fail to comprehend its full meaning or critical significance. This failure could occur because the signals' strength or clarity does not facilitate discrimination from the general cockpit noise context or because the number and complexity of cockpit displays and tasks does not allow sufficient time for assessment of the relative significance of the symbol. Decision is the information processing phase in which the pilot selects from a repertory of alternatives the particular action that is appropriate. A danger signal may be perceived and its importance may be comprehended, but the correct action may not be elected. Finally, a failure may occur when the pilot implements the selected action. The physical action itself may be poorly coordinated or incorrectly performed.



Each of the four areas of pilot information processing in the cockpit, perception, comprehension, decision, and action can be affected by the design and operation of cockpit systems. Standard instruments, long familiar to the pilot, and standard usage of coded knobs and dials will increase the probability of perception. Signals arranged in a customary array and received without excess competing demands for pilot attention will be more easily comprehended. Errors in decision-making may stem from cockpit systems that are more complex or attention-demanding than is necessary. A fuel starvation signal, a sputtering or dying engine, is quite commanding and unequivocal. And with a fuel system that does not clearly indicate the quantity of fuel remaining in each tank or which tank is presently on line, an information processing failure consisting of an incorrect decision is likely. Finally, an action selection failure may be promoted by cockpit arrangements that facilitate pilot confusion of one control with another, so that the pilot who intends to do one thing actually does something else. Standard arrangements and logic of actuation are clearly means of reducing action errors.

The preceding discussion of principles of safety makes a case for the safety enhancement that can be obtained by increasing standardization in the cockpit. It is recognized that this is not the only way to reduce accidents. Improved levels of pilot proficiency and currency, plus the avoidance of flight in hazardous environments are complementary, and statistically are more productive means of improving safety.

The particular attraction of attacking the accident problem at the level of cockpit standardization is twofold. First, the standard use of well designed and human engineered cockpit systems may not cost any appreciable sum in the long run. A good fuel selector system is not necessarily more costly than a poorly designed one. Second, safety increments obtained by increasing standardization of cockpit systems would add to the ease and convenience of pilotage, whether in the training phase or in later experience. Any increment of safety that can be obtained by using well designed systems rather than poor systems and that results from standard, convenient, and easy-to-use cockpit systems rather than variable, demanding, and hard-to-use systems would be worthwhile, even though not a panacea.

#### GOOD DESIGN PRINCIPLES.

Standardization by itself is very important in any complex task where performance is based on past training and experience with similar or analogous systems. An everyday example is found in the typewriter keyboard. Even a beginning student of touch typing can determine that the layout is far from optimum. It does not spread the workload equitably among the fingers, but standardization is of such overwhelming importance in typing that we retain the traditional layout. The cockpit of an airplane presents both traditional tasks for which there are well established population stereotypes, utilizing reliable habits, and also novel displays and controls that have been created specifically for individual aircraft types. For each of these, the old and the new, there are generally accepted rules of human engineering that tend to insure that the system is easy to learn and use, is resistant to serious error, and recognizes the special information processing capacities and frailties of human pilots.

When selecting a cockpit system for an "old" or traditional task, the paramount considerations are:

1. Anthropometric compatibility should be assured. The size, reach, and strength of the prospective pilots must be considered.
2. Unequivocal indicators and feedback must be used. The pointer end of a selector handle must be clearly identified, for example, and the status information required to continue a closed-loop control system must not be masked.
3. All systems must follow population stereotypes as to logic of actuation, direction of increase, and "natural" relations such as turn left to select the left.
4. Positive detents or other provisions to bar inadvertent actuation must be provided on all controls which, if misused, can create a hazardous condition.
5. Provision should be made for testing the status of systems, and indicators should have a clearly identifiable failed state.
6. Standardization should cover, where appropriate, the location, size, color coding, shape, labeling, feel, logic, and arrangement in relation to related systems of all important devices and systems.

In the case of a novel aircraft system without a common analogy in the experience of most inexperienced pilots, a set of general design objectives are:

1. The design should be based on a human factors study of the purpose of the device and how the pilot will use it.
2. Information processing sequences should be considered so that there is maximum distinctiveness and separation of confusable and/or incompatible systems.
3. Simplicity of display and action should be sought, recognizing that the system may have to be used in excess workload or "panic" situations.
4. The perceptual capability of the human in recognizing patterns of information should be considered in display design.
5. The response limitations of the human should be considered in design so that the pilot is not required to perform difficult and demanding coordinations.
6. Planning aids and feedback from response should be included.

As in the example of the typewriter keyboard, it is possible to detect an occasional conflict between good design and capitalization on the benefits of standardization. Some aircraft systems have evolved and become nearly

standard without necessarily incorporating an optimum application of all the design guidelines that have been mentioned. Hence, the concept of good human engineering of cockpit systems cannot be treated as absolute any more than can standardization itself be elevated to that status. Guiding concepts of design are just that, guidance, not law. Likewise, total standardization of cockpit systems could be accomplished only at the sacrifice of the wide variety of aircraft types and uses, a sacrifice that would be as useless as seeking safety by grounding all aircraft in anything other than perfect weather. What must be done in the evolution of better regulations and design practices is to balance the demands of optimum human engineering design and the benefits of standardization with a keen appreciation of what is feasible, practical, and cost effective.

### APPROACH

This project was conducted by FAA's National Aviation Facilities Experimental Center (NAFEC) engineers, human factors and flying specialists working with elements of the general aviation community, particularly flying schools, aviation-oriented universities, and the major manufacturers of FAR 23 airplanes.

Early efforts in the project were directed at the identification of those cockpit design areas most in need of better standardization, but yet satisfying practicality considerations.

The remainder of the effort consisted of the collection and analysis of data which would justify regulatory or design practice action to achieve improved standardization in the areas identified.

### IDENTIFICATION OF NONSTANDARD COCKPIT AREAS.

Following a background study consisting of a regulatory and literature review, a survey of current cockpits, and interviews with GAMA officials and consultants, the broad subject of cockpit design was divided into 12 areas:

(1) Cockpit General, (2) Flight Controls, (3) Powerplant Controls, (4) Fuel Management System, (5) Flight Instruments, (6) Engine Instruments, (7) Navigation and Communication System, (8) Landing Gear, (9) Electrical System, (10) Cockpit Lighting Systems, (11) Emergency Systems, and (12) Miscellaneous.

The detailed list of features is shown in table A-1 of appendix A. For example, the Cockpit General area was subdivided into: Dimensional Criteria, Seat Belts and Restraints, Windscreen Visibility, Ventilation and Environment, Doors-Access, Noise, Placards-Marking-Manual, and Heater-Defrost Control. This subdivision produced 101 design features. The initial factors for evaluation fell into four areas: Anthropometric Factors such as location, accessibility, and size; Visual Factors such as visibility, readability, and color coding; Population Stereotype Factors such as logic of operation and confusion factors; and Operating Feedback Factors such as ease of operation, shape, and feel. A subject interview briefing and a data collection form were developed.

Data were collected during visits to three large flying schools and four major universities and in interviews with 82 pilots, all active in general aviation and ranging in experience from advanced student to highly qualified instructor. This data collection phase identified those cockpit design features in current model general aviation aircraft that either were not standardized to the degree thought optimum by experienced pilots or had the potential to induce pilot errors. An illustration of the first type of feature drawn from the area of powerplant controls is carburetor heat. Many pilots stated that the carburetor heat control should be standard across different aircraft models. Among the factors said to be deficient in standardization were: (a) the location of the carburetor heat control, an anthropometric factor, (b) variability in color coding, a visual factor, (c) variable logic of operation (up-down, push-pull, etc.), a population stereotype factor, and (d) shape and feel variations, an operating feedback factor. Hence, carburetor heat controls were said to fail of reasonable standardization on all classes of factors.

The seat latching mechanism is an illustration of a cockpit feature identified by the pilots as sometimes poorly designed and providing the potential for pilot error. This feature was noted by a number of pilots who said that when an aircraft was rotated on takeoff, the seat might slip aft causing the pilot to mishandle the control yoke. This could happen, the pilots said, because it was difficult to ensure that the seat adjusting mechanism was latched in a positive detent. If between locked positions, it could slip to the full aft position on rotation of the aircraft. To prevent such an incident, experienced pilots make it a practice to push against the seat before applying take-off power. Subjects said this should not be necessary and that potential accidents could be avoided if it were a requirement that the seat adjusting mechanism be designed to snap automatically into the next detent if inadvertently left in an intermediate, unlocked position.

To acquire additional data, the project team visited the factories of several GAMA members. The cockpits of current production models were examined and compared, and engineers explained the differences between models. In some instances the engineers explained why the particular cockpit systems could not be standardized, or what the costs would be to attain greater standardization. This information was combined with the pilot survey data.

The tabulated results of pilot and instructor interviews are presented in table A-2 of appendix A. In this table, the comments and suggested cockpit features needing standardization are arranged in descending order of frequency of criticism. For example, the greatest agreement that increased standardization was warranted was for the first item, fuel selectors, with 59 of the 82 contributors citing some aspect of that feature. In contrast, only one comment was received on the need for standardization of the next-to-last item, the outside air temperature (OAT) indicator.

The items listed in table A-2 of appendix A are numerous and diverse. Consideration was limited to those items selected by 50 percent or more. This reduced the list to 25 features, each with at least 41 comments.

A further filtering based on the primary criterion, safety, and practicality considerations resulted in the final list of nine cockpit features:

1. Seats and Restraints
2. Seat Latches
3. Door Handle, Latches, Locks
4. Fuel Management
5. Powerplant Controls
6. Flight Instruments
7. Powerplant Instruments
8. Instrument Lighting
9. Circuit Protective Devices

Table A-3 of appendix A further subdivides the nine selected areas of cockpit design into the specific features cited by the pilots as requiring standardization, and shows the number of citations for each feature.

#### ANALYSIS OF SELECTED COCKPIT FEATURES.

The project team conducted a detailed review of the literature applicable to design features of general aviation aircraft cockpits. For example, tests and studies conducted by FAA laboratories at the Aeronautical Center in Oklahoma City and at NAFEC showed the safety benefits from greater use of upper torso restraints (references 7 and 8). Standardization documents applicable to aircraft classes other than FAR 23 aircraft provided information on available designs for safety harnesses that have been accepted in practice (reference 9). Civil aviation accident summaries were reviewed to identify accident causal factors. Analyses were made of the NTSB data bank in Washington, and several hundred selected reports of accident investigations were studied.

The latter phase of the project concentrated on the nine selected areas of cockpit design and involved the collection and analysis of data that might justify the requirements for increased standardization and indicate the answers to problem areas where such design information is available. The effort was specific but covered a diversity of information sources. Technical reports, standardization documents, scientific journals, military specifications, human engineering guides and other documents were reviewed. The study of accident investigation reports was redirected; accidents that had occurred in calendar years 1969 through 1974 were tabulated, to the extent possible, with causal factors aligned with the nine design areas.

Pilot error accidents were drawn from the NTSB files and reviewed to determine if lack of standardization in cockpit design was a significant contributory factor. Reports of accidents in which the pilot survived often contain a statement by the pilot. In some cases these first-hand analyses provided information relative to the lack of standardization. In other cases it was not possible to retrace the sequence of events. A combination of factors was often present such that a review of the events made it clear that stress and excess workload were present, and that weather and system malfunctions may have added to the problems of the pilot. Hence, the study of the accident

dockets was often valuable in giving insight into what could happen in a stress situation rather than pinpointing exactly what did happen. Since it is not always feasible to pinpoint the exact cockpit factor precipitating an accident, a statistical tabulation by individual cockpit features is not always practical. However, illustrative accident sequences may be obtained, and if it is clear that a particular thing went wrong once, it is reasonable to infer that something similar could happen on other occasions, although no massive number of accidents can be assigned to that specific factor. Because of these considerations, in later sections of this report accidents will sometimes be discussed as illustrations, rather than as statistical evidence for the importance of particular factors.

#### REPORT FORMAT.

This report is organized into individual sections which treat the nine identified areas of cockpit design. The first three sections cover cockpit design areas within the category of cockpit functions that involve housing, sheltering, and protecting the pilot: seats and restraints, seat latches, and door mechanisms. The next six sections cover the design areas which involve the man-machine interface provided to support flight control: fuel management, powerplant controls, flight instruments, powerplant instruments, instrument lighting, and circuit protective devices.

Arrangement of the material in each of these nine sections allows the reader to study the individual section apart from the full report. Recommendations for each of the nine areas however, are combined and briefly discussed in the "SUMMARY OF RESULTS" chapter.

### SEATS AND BERTHS

#### THE PROBLEM.

In a study of more than 900 general aviation accidents, over 50 percent of the aircraft involved had cabin structures which remained intact or suffered only minor distortions. However, in these "survivable" accidents more than 25 percent of the occupants sustained fatal or serious injuries (reference 10). The fatalities and serious injuries were caused primarily by head and/or face impact with the instrument panel, aircraft controls, or parts of the cabin interior when occupants were restrained only by the standard lap seat belt. The second most frequent body injury involved spine/neck injuries brought about by the compression load imposed on these areas when occupants were subjected to forward or lateral forces occurring in the crash.

#### REGULATORY HISTORY.

Newly manufactured general aviation aircraft are factory equipped with standard lap seat belts for forward facing seats; the majority have some type of upper body restraint, generally a separate diagonal across-the-chest belt for the

front seats. In other aircraft this equipment generally is optional. The upper torso restraint (shoulder harness) was not a mandatory requirement under previous FAR 23.785(g) 2 and 3. That regulation allowed, as an alternative to the seat belt-upper torso restraint, either a seat belt plus the elimination of injurious objects within the striking radius of the head, or a seat belt plus an energy-absorbing rest.

The problem of head protection in this class of aircraft was addressed specifically by Amendment 23-7 "Small Airplane Type Certification Requirements" which added subparagraph g to FAR 23.785, effective September 14, 1969. But the amended regulation applied only to applications for type certificates submitted after the effective date, and thus affected less than 5 percent of new production airplanes in 1976. Furthermore, upper torso restraint was still not a requirement since the two alternatives previously mentioned (23.785(g) 2 and 3) were used for protecting occupants from head injury.

Subsequent to the adoption of Amendment 23-7, the FAA continued to review the complex area of occupant restraint and crashworthiness of small airplanes. The FAA also received suggestions for improved protection of occupants from injury in a crash or emergency landing. These included recommendations by the NTSB and a petition in which Mr. Ralph Nader requested the FAA to improve the crashworthiness of small aircraft by requiring shoulder harnesses and improved cabin interior design.

In considering the data and recommendations received concerning the type certification requirements for small airplanes, the FAA believed that additional crash protection was needed for occupants. These requirements for aircraft certificated under FAR 23 were published in an NPRM, Docket No. 10162, Notice 73-1, "Crashworthiness for Small Airplanes," on January 31, 1973 (reference 11). This document proposed amending FAR 23 to require the installation of shoulder harnesses in airplanes manufactured 1 year from the effective date of the proposed amendment and also apply to airplanes made prior to the effective date if they have structural provisions for the attachment of the harness. The NPRM further proposed that FAR 23 cabin interiors be designed to protect occupants from injury caused by contact with interior objects and that Part 91 (reference 12) be amended to require that crew members have their shoulder harnesses fastened at all times.

NPRM 73-1 elicited over 200 comments from interested persons and organizations. Fifty-five percent of the comments reflected a negative attitude to the NPRM. The major objection to the proposed rule was opposition to mandatory full-time use of the upper torso restraint. Other objections included the costs of installation, especially for retrofit, discomfort, and the possibility that some aircraft controls would not be easily accessible when the upper torso restraint was employed.

Comments favoring the proposed rulemaking often had qualifying statements concerning the type of body restraint preferred, assurance of pilot comfort and mobility for easy access to all cockpit controls, and no restrictions to cabin egress. Comments and opinions similar to those mentioned above were expressed by the pilots and flight instructors interviewed in the initial phase of this study. A discussion of the comments elicited by this proposed rule is in a later section of this report.

In April 1975, the International Civil Aviation Organization (ICAO) forwarded to the Interagency Group on International Aviation, Department of Transportation (IGIA-DOT) a request for "Comment on Proposed Amendments to Annex 6, Part I and Part II--Provisions for Flight Crew Safety and Pilot Incapacitation." The proposals provided for additional protection of all flight crew members by installation of a safety harness for each flight crew seat. This provision did not explicitly exclude small aircraft and appears not to have been limited to the transport category usually associated with ICAO. NPRM 73-1 was still under consideration at the time ICAO requested provision for a safety harness for each crew seat. The proposed United States standard would, of course, have made shoulder harness installation mandatory, but to avoid a difference between the pending United States standard and ICAO's, the draft reply to the ICAO Secretariat stated that "the United States does not wish to see the proposed recommendation raised to the status of a standard." Hence, the United States did not reject the content of the ICAO proposal, but indicated a preference for a nonmandatory recommendation without the force of law.

#### ACCIDENT DATA.

A review of NTSB aircraft accidents for the years 1970 through 1974 (reference 13) indicated that general aviation FAR 23 aircraft (i.e., aircraft weighing less than 12,500 pounds maximum certified takeoff weight) were involved in 22,296 accidents. This number of accidents resulted in 6,936 fatalities, 3,480 serious injuries, 5,355 aircraft destroyed, and 16,969 substantially damaged.

NTSB documents 59 first-type accident causes by injury and damage index in the annual review of aircraft accident data reports. From this list of 59 first-type causes, the most common 24 are shown in table 1. They account for approximately 90 percent of the general aviation accidents that have occurred within the 5-year period. Table 1 also shows for each of the 24 first-type accident causes the percent involving fatal/serious injury and thus the relative seriousness of injuries occurring in these first-type accidents. For example, as seen in table 1, of the 416 spin accidents (No. 1) 384 or 92.3 percent were fatal/serious injury accidents. Similarly, the 4,954 accidents resulting from engine failure (No. 10) included 979 fatal/serious injury accidents, a 19.8-percent fatal/serious injury rate. While this rate is low compared to those of the first nine categories, engine failure accidents rank first for total number of accidents, serious injury accidents, aircraft destroyed, and substantial damage to aircraft. Furthermore, the engine failure category ranks third for the number of fatal accidents. Therefore, the following analysis includes the engine failure accident in the group of 10 first-type accident categories.

For an analysis of the accident data of table 1, the accident types are divided into two major parts: those from numbers 1 through 10, and those from 11 through 24. The division is based on the relatively high percentage rates of fatal/serious injury accidents of the first 10 types compared to the lower fatal/serious injury accident rates of the last 14 types.



TABLE 1. PERCENTAGE RATES OF FATAL/SERIOUS INJURY FOR FIRST-TYPE ACCIDENTS (1970-1974)

First Type Accident	Number of Accidents by Type of Injury				Total	Percentage of Fatal/Serious Injury Accidents	Aircraft Damage	
	Fatal	Serious	Minor	None			Destroyed	Substantial
1. Spin	313	71	23	9	416	92.3	342	74
2. Collision with grd/water(uncnt)	664	85	69	121	939	79.8	728	210
3. Airframe failure in flight	190	19	27	54	290	72.0	208	82
4. Spiral	21	16	7	8	52	71.0	33	19
5. Midair Collision	143	28	19	70	260	65.7	140	122
6. Collision with grd/water(cont)	367	114	113	224	818	58.8	476	339
7. Collision with trees	370	143	124	266	903	56.8	520	383
8. Stall	389	199	166	291	1045	56.3	544	500
9. Collision with wires/poles	158	159	149	303	769	41.2	333	436
10. Engine failure	386	593	1072	2903	4954	19.8	959	3990
11. Mush	44	101	163	476	784	18.3	180	604
12. Undershoot	40	64	109	501	714	14.6	90	622
13. Collision with dirt bank	1	13	16	82	112	12.3	12	100
14. Rollover	4	2	18	32	56	10.7	11	45
15. A/C-A/C Collision on ground	8	7	20	132	167	9.0	12	141
16. Overshoot	24	65	144	764	997	8.9	72	925
17. Gear down landing in water	1	0	3	8	12	8.0	1	11
18. Collision with fence/posts	4	8	37	226	275	4.0	19	256
19. Hard landing	9	53	148	1437	1647	4.0	62	1581
20. Noseover	6	11	77	625	719	2.0	24	694
21. Ground/water loop=swerve	10	51	272	2632	2965	2.0	85	2879
22. Wheels up landing	2	4	4	581	591	1.0	8	582
23. Gear collapsed	2	3	41	410	456	1.0	17	439
24. Gear retracted	0	0	3	294	297	0.0	5	291
Total Types, 1-24	3136	1809	2824	12449	20238	24.3	4881	15323
Subtotal Types, 1-10	3001	1427	1769	4249	10446	42.3	4283	6135
Subtotal Types, 11-24	155	382	1055	8200	9792	5.4	598	9170
Percentage Fatal/Serious Types, 1-10	95.2	79.9	62.7	34.1	51.6		87.7	40.2
Percentage Fatal/Serious Types, 11-24	4.9	21.1	37.3	65.9	48.4		12.3	59.8

Fatal Injury: Any injury which results in death within 7 days.

Serious Injury: Any injury which: (1) requires hospitalization for more than 48 hours, commencing within 7 days from the date the injury was received; (2) results in a fracture of any bone (except simple fractures of fingers, toes or nose); (3) involves lacerations which cause severe hemorrhages, nerve, muscle, or tendon damage; (4) involves injury to any internal organ; or (5) involves second or third degree burns, or any burns affecting more than 5 percent of the body surface.

Destroyed: Damage to an aircraft to the extent that it would be impractical to return it to an airworthy condition.

Substantial Damage: Damage or structural failure which adversely affects the structural strength, performance, or flight characteristics of the aircraft, and which would normally require major repair or replacement of the affected component.

Under the fatal/serious injury columns for the 24 accident types listed, there were a total of 3,156 fatal and 1,809 serious injury accidents. The sum of these two accident injury classifications is 24.5 percent of the total 20,238 accidents.

Three thousand and one fatal and 1,427 serious injury accidents were attributed to first-type accidents 1 through 10. Combined, they account for 42.3 percent of the total 10,446 accidents. The 3,001 fatal accidents and 1,427 serious injury accidents, respectively, account for 95.1 percent of fatal and 79.9 percent of serious injury accidents of the first group (1-10) of first-type accidents.

Similarly, the accident types of numbers 11 through 24 were responsible for 155 fatal and 382 serious injury accidents, which when combined, represent 5.4 percent of the total 9,792 accidents occurring in this group. The 155 fatal and 382 serious injury accidents, respectively, account for 4.9 percent of fatal accidents and 2.1 percent of the serious injury accidents.

The columns showing aircraft damage indicate that the first group of 10 accident types account for 4,283 aircraft destroyed or 87.7 percent of all aircraft destroyed, while the accident types of the second group (types 11 through 24) resulted in 599 aircraft or 12.3 percent destroyed.

Of the 24 accident types listed, the first group of 10 may be considered major type accidents, i.e., the nature of the accident was such that the ultimate forces imposed on the aircraft probably exceeded the design forces required under FAR 23.561 (reference 1) to protect occupants from serious injury under emergency crash landing conditions. The second group of accidents, types 11 through 24, may be regarded as accidents of a less catastrophic nature, assuming that the ultimate forces imposed on the aircraft structure did not exceed the specified design forces. The data of table 1 support these assumptions when one compares the relatively high percentage rates of fatal/serious accidents and aircraft destroyed in the first group of 10 accident types with the relatively low fatal/serious injury accidents and number of aircraft destroyed in the second group of 14 accidents. The number of aircraft destroyed in group 1-10 type accidents (4,283) represents 87.7 percent of the total number of aircraft destroyed, while the number of aircraft destroyed in group 11-24 type accidents (598) represents 12.3 percent of the total, a ratio slightly greater than 7 to 1. These figures indicate that the majority of the group 11-24 type accidents are of less serious nature than those of the other group. It is reasonable to assume that, if all of the aircraft involved in group 11-24 type accidents had been equipped with upper torso restraints and if the occupants had been wearing them, the number of fatalities or serious and minor injuries would have been reduced considerably. It is also possible that upper torso restraints would have had a favorable, if not as large, effect on the group 1-10 type accidents.

The records of accidents compiled by the NTSB ordinarily do not specify the type of injury sustained by the occupants of aircraft involved in accidents other than to classify accident injuries as either fatal, serious, minor, or

none. Thus, a comparison of bodily injuries sustained with shoulder harnesses installed and worn versus bodily injuries sustained with no shoulder harnesses installed was not possible.

#### LITERATURE REVIEW.

A review of the literature relevant to crashworthiness of small general aviation aircraft and related information on seats, berths, and restraints shows a significant number of head, face, upper torso, and extremity injuries attributed to impact with the instrument panel, cabin sides, and flight controls. (Of more importance is the fact that a large number of the resultant injuries occurred in accidents in which the cabin environment remained substantially intact (the aircraft cabin structure sustained a 15 percent or less reduction of its original volume).

In an effort to obtain as much objective data as possible, the project team reviewed more than 200 studies, research reports, papers, journals, and articles pertinent to body restraints and the associated areas of crashworthiness design, crash impact variables, kinematic behavior of the human body during deceleration, and trauma associated with light aircraft crashes.

Hasbrook's study (reference 10) of 913 general aviation accidents showed that 56.1 percent of the aircraft involved either suffered no structural damage to the cabin or only minor distortions. Yet, 29 percent of the occupants of these "survivable" accidents sustained fatal or serious injuries. (A survivable accident is one in which the structure in the occupants' immediate environment remains substantially intact throughout the impacts, and in which the forces transmitted to the occupant through his seat and restraint system do not exceed the impact (g) tolerances of the human body.)

A similar study (reference 14) of Army aircraft accident data revealed that 61 percent of the fatalities incurred were due to crash impact, and 25 percent of these fatalities were due to head/face injuries which were not only the most lethal but most frequent. It was recommended that efforts should continue to minimize head and spinal injuries..."the lap belt by itself does not provide upper torso restraint for minimizing occupant structure strike injuries and reducing spinal injuries in vertical crash forces." The report, concerning 248 occupants involved in light plane crashes, continued: "...yet one out of four occupants were killed. Injuries stemmed from flailing of the body parts within the occupants' environment.... The lap belt restraint plays only a moderate role in reducing injury severity...."

Another report by the Army Research Command (reference 15) stated: "Full protection of seat belt only restraint can be realized only when the occupant has an unobstructed path for his flailing extremities and upper torso. If this condition does not exist, the protection offered by the lap seat belt may not be limited by g factors, but by the injurious aspects of the occupants' environment...seat belt injuries in general should not be considered proof against seat belt usefulness, but as evidence of its necessarily limited protective value when compared to restraint systems that offer better load distribution over the entire skeleton."

An FAA report (reference 7) concerning the investigation of 78 light aircraft accidents indicated that 17 aircraft were destroyed and 11 were partially destroyed, and in 50 aircraft the cabin remained intact. Of the 50 survivable-type accidents involving 111 occupants, 26 were killed, 37 were seriously injured, 6 received minor injuries, 21 received no injury, and injury to one occupant was unknown. The majority, if not all injuries, were results of head-face-torso impact with the instrument panel or cabin interior structures. The approximate 25 percent fatality index rate is in accord with Hasbrook's information.

Carr and Singley (reference 16) reported that 61 percent of all fatalities are due to impacts, and approximately 25 percent of all fatalities are due to head and face injuries.

J. Swearingen, in reference 17 states: "Crash safety design is far behind that of the automobile.... Death rates per 100 million passenger miles in aircraft are at least seven times those for automotive transportation. Detailed analyses indicate that general aviation aircraft with rigid instrument panels studded with heavy instruments, protruding knobs, and sharp edges, along with a lack of slow return padding and very inadequate restraint equipment, are producing fatal or serious injuries during low cabin crash decelerations of as little as 3-4 g's.... Tests indicate a complete restraint system is significantly superior to the 'seat belt only' restraint system." In another two-year study (reference 18) pertaining to acceptance tests of various upper torso restraints, Swearingen found that people can be motivated to accept and use torso restraint equipment provided specific design criteria are adhered to. Criteria include comfort, neatness of appearance, ease of stowage, and ease of donning and removing. Inertia reel design should be included for ease of motion.

Similarly, R. A. Hughes (reference 19) reports: "It is deduced that poor acceptance of the currently fixed shoulder harness in automobile systems stems from the failure to meet certain qualitative specifications relating to comfort, fit, ease of use, and freedom to move. A late result has been increased demand for passive restraint systems which require no action on the part of the vehicle occupant."

Hughes also concludes that: "Effective personnel restraint systems have been developed for general aviation. These systems stress safety, comfort, economy, ease of installation, and generation of user confidence. Inertial or force sensing reels and single point buckles are integral parts of the system. The system for personal and private flying adds comfort and convenience to the familiar automotive-type harness, while the system for business aircraft or other aircraft with structural seats utilizes the experience gained on thousands of commercial transport aircraft."

Flight Safety Foundation (FSF) reported in an Accident Prevention Bulletin (reference 20) that: "Crew members are exposed to a more injurious environment than most passengers, and head injuries to cockpit personnel can be the cause of serious, even fatal injury. Only adequate upper torso restraints can prevent or minimize these injuries.... Human tolerance to transverse deceleration is increased by using a shoulder harness in conjunction with a seat belt because it keeps the spine perpendicular to the direction of the crash force."

In 1972, NAFEC conducted a series of 22 dynamic tests on general aviation occupant restraint systems (reference 8), by studying the longitudinal deceleration/time response of anthropometric dummy occupants. It was demonstrated that the lap belt/shoulder harness restraint system offered occupants successful restraint at occupant inertia force levels substantially above the current regulatory level. The tests, preliminary in nature, warranted continuation of the test program in that "...restraint systems showed promise for regulatory inclusion, by virtue of the fact that results were achieved with restraint systems offered as options in recent years, requiring minimal weight increase with fuselage reinforcement adaptable to retrofit as well as new assembly."

There is little doubt that seat restraints have grown in availability and use in other vehicular modes. The initial resistance to wearing belts has declined gradually due to safety education and the improvement in convenience and utility of using the restraints themselves.

The first belts were two piece, manually adjusted and nonretractable. Evolution of a combined lap and upper-torso restraint system, consisting of one movable part and requiring no adjusting or storing action, has aided acceptance. This simple system is presently found in most current automobiles and new general aviation aircraft. While it represents a major improvement over the lap belt, it is not the ultimate in protection, as evidenced by several studies of comparative effectiveness. Significant reductions in automobile casualties have been attributed to belt wearing, but experimentation with simulated aircraft crashes suggests that a further significant increment in safety is provided by the dual-loop-around-the-shoulder system, often characterized as the "aircrew" restraint design (reference 16). The dual loop system provides greater lateral protection and better deceleration load distribution than the across-the-chest or Sam Browne type.

An Australian study (reference 21) revealed:

1. "The compulsory wearing of belts in Victoria is now being observed by 85 to 90 percent of the drivers in the country and metropolitan areas, respectively.
2. "The overall vehicle driver casualties fell by about 14 percent due to belt wearing...."
3. "Detailed examination of accident data shows seat belt wearing to have a casualty reduction potential in a variety of accident types. However, the effectiveness could be improved by vehicle design to give better lateral protection to occupants."

The consensus of many reports is that:

1. A significant number of aircraft occupants involved in light aircraft accidents are sustaining fatal and serious injuries in "survivable-type" crashes.

2. Twenty-five percent or more of these injuries are attributable to unrestrained head, face, or body impact with the instrument panel, flight controls, or surrounding structure of the cabin environment.
3. The lap seat belt by itself has a limited protective value and does not provide upper torso restraint for minimizing head/face injuries and reducing spinal injuries in survivable-type light aircraft crashes.
4. A single diagonal chest strap used in conjunction with a lap belt can reduce injury severity and is more effective as a restraint than the lap belt alone. However, the single diagonal belt/lap belt is not the optimum restraint system since it will not prevent head impact during forward and lateral decelerations.
5. Effective upper torso restraints are available from aircraft manufacturers and aircraft products manufacturers.
6. Aircraft occupants can be motivated to wear upper torso restraints provided the restraint system is designed to offer adequate comfort, pilot mobility, neatness of appearance, ease of stowage, and ease of donning and escape.

#### CURRENT STATUS OF RESTRAINT SYSTEMS.

Members of the project team visited three major manufacturers of general aviation aircraft to inspect current production line aircraft and to obtain first-hand information from engineering personnel on current design thinking, problems, and status of shoulder harness installation.

The chief engineer of one of the aircraft plants stated that in addition to the lap belt, upper torso restraints for front seats are now standard equipment on all of their aircraft models. The installed restraints generally were the diagonal "Sam Browne" chest belt type. Some models inspected were equipped with inertia reel restraints; others offered them as an option.

Ideally, the diagonal chest-type restraint anchor point is located on the outboard side of the cabin structure, behind the occupant's outboard shoulder. This anchor point then allows the upper torso restraint to pass over the outboard shoulder and fasten inboard at the occupant's hip as shown in figure 2. This arrangement is recommended to minimize body impact with the side structure of the aircraft cabin in the event of an emergency crash landing.

Aircraft structural design in at least one model precluded this anchor point arrangement because of the location of the doors. In this model, the anchor point for the upper torso restraint was located in the overhead behind and midway between the two front seats. This arrangement brings the upper torso restraint across the chest from the inboard shoulder to the outboard hip; while restricting forward body movement in the event of rapid deceleration, this configuration provides little, if any, protection for body and head impact in forward/sideward decelerations.

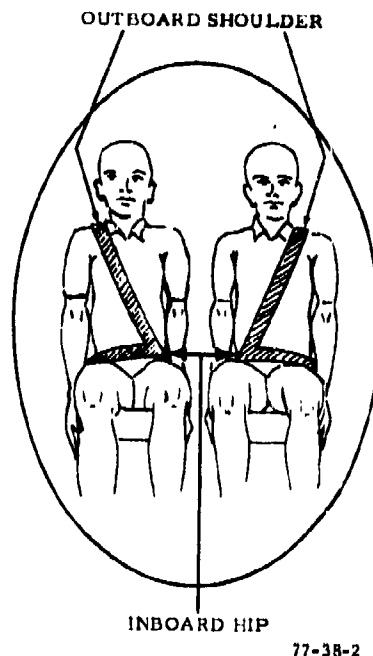


FIGURE 2. UPPER TORSO RESTRAINT INSTALLATION--DIAGONAL BELT

The vice-president of engineering of another aircraft company told the team that all current models of their aircraft have upper torso restraints with inertia reels as standard equipment for front seat occupants.

Recent literature for a third aircraft company advertises that shoulder safety belts with inertia reels are standard front seat equipment on at least three of the 1977 single-engine aircraft models.

In the United Kingdom (UK), the combined efforts of two manufacturers of aircraft products resulted in the development and manufacture of an inertia-reel full harness which consists of two over-shoulder, integral restraints that cannot be unhooked to leave just the lap belts fitted. Both lap and shoulder straps are locked by a single clasp and are adjustable (figure 3).

The harness has been approved by the UK Civil Aeronautics Administration (CAA), but more significant is the fact that the UK CAA has required that the front seats of all British-registered aircraft should, by January 1978, carry shoulder restraints of either a diagonal belt or full harness, as per Great Britain Air Navigation Order 1976, Schedule 5, Scale AB.

The project team examined several typical current production aircraft which indicated that aircraft manufacturers are concerned with occupant safety and are installing, as standard equipment, some form of upper torso restraint in current production aircraft.

The variety of occupant restraints examined included inertia and noninertia types, single diagonal/lap belt combination, single diagonal belt/separate lap belt, and dual over-the-shoulder straps/separate lap belt. Belt buckle coupling arrangements and locations varied as did the location of the upper torso restraint anchor points. The noninertia but adjustable restraints for front seat occupants generally are stowed inconveniently in clips above the front side windows; consequently this type usually remains unused.



77-38-3  
FIGURE 3. INTEGRAL RESTRAINT WITH DUAL BELTS

Despite the dissimilarities, the restraints installed in these new aircraft are a major improvement over aircraft equipped with only lap/seat belts.

NPRM 73-1 (REFERENCE 11). The accident data show that a significant number of people involved in aircraft accidents are fatally or seriously injured because of unrestrained head-face-body impact with portions of the aircraft cabin interior. Innumerable studies offer overwhelming and irrefutable evidence that the lap seat belt, by itself, has a limited function in protecting occupants from fatal or serious injury in light aircraft impact accidents. Manufacturers, cognizant of the need for improved occupant safety, are installing upper torso restraints in newly manufactured aircraft. It is surprising then that the FAA NPRM requiring the installation and use of shoulder harnesses met with such opposition.

FAR 23.785 was submitted as a section of NPRM 67-14 in 1967 (Federal Register Vol. 32 No. 69, April 11, 1967). During the period open for comment, four responses reflected the following opinions:

1. Unqualified yes. "...changes should result in a safer aircraft."
2. Qualified yes. "...but define injurious object."



3. No. "...shoulder harnesses should continue as optional equipment."
4. No. "...until pilots are aware of the benefit of these devices, installed belts will not be used."

The comments received were from two aircraft manufacturers and two organizations representing aircraft manufacturers.

Subsequently, FAR 23.785 of NPRM 67-14 was adopted as originally proposed under Amendment 23-7 and became effective September 14, 1969. FAR 23.625 (Fitting Factors) and 23.1413 (Safety Belts and Harnesses) were amended to include the word "harness." No revisions were made to FAR 91 as there were no proposals to amend that part.

NPRM 73-1 (Federal Register 38-2985, January 31, 1973), relevant to shoulder harness installation and use, proposed amendments to FAR 23 and 91. NPRM 73-1 elicited over 200 comments from the general aviation public, with over 100 responses opposed to the proposal. The chief objections to the NPRM are:

1. Over-regulation
  - a. Oppose being told what to wear.
  - b. Oppose mandatory nature of the proposed regulation.
  - c. Unenforceable regulation.
  - d. Impossible to regulate safety.
  - e. Invasion of people's rights.
2. Cost
  - a. Cost for installation and retrofit.
  - b. Drives cost of airplanes up.
3. Operational (Mandatory) Use
  - a. Confining
  - b. Cumbersome
  - c. Unsightly
4. Dangerous
  - a. Impede pilot mobility to reach all controls and equipment.
  - b. Restrict head mobility in looking out for other aircraft.
  - c. Impede egress.
  - d. Diagonal belt can break neck.

The difference in the number of responses to the two NPRM's is because NPRM 67-14 imposed a requirement only on the aircraft manufacturer, while NPRM 73-1 sought to impose a requirement on both manufacturer and general aviation public.

Since current shoulder harness development technology has been improved considerably, objections 3 and 4 are not substantial enough to warrant withdrawal of NPRM 73-1. Of the first two objections, there are two substantial arguments against the adoption of the NPRM.

A report prepared by the MITRE Corporation (reference 22) presented a preliminary analysis of all civil aviation accidents which occurred within the United States, its territories, and possessions during the 9-year period from January 1964 to December 1972. The accident data were derived from NTSB records and included accident data for the four user classes of air carrier, small air taxi, corporate/executive, and small general aviation aircraft. Considering only the data pertinent to small general aviation aircraft, figure A-4 of appendix A, shows the accidents and related fatalities that occurred during the 9-year span. The total of small general aviation aircraft accidents accounted for 92.6 percent (42,567) of the total accidents (45,946) and for 74.4 percent (9,468) of the total fatalities (12,719). What is significant is the fact that of the single aircraft accidents that occurred under normal operating conditions, the combination of takeoff and landing accidents (22,229) accounted for 82 percent of the 27,100 accidents.

Thus these accident figures substantiate the objection to the proposed requirement for flight crew members to wear the installed harness at all times while at their stations. They also reinforce the requirement for wearing them during takeoff and landing; these are flight phases of high accident frequency.

The opposition to the proposed retrofit provision of the NRPM also appears justified. Table 2 shows the population of registered general aviation aircraft by type for the years 1969 through 1973. Note that the first three aircraft types, single-engine one-to-three place, single-engine four-place and over, and multiengine reciprocating, comprise, respectively, 33 percent, 50 percent, and 12 percent (total 95 percent) of the general aviation fleet. A projection of these percentages to the estimated 1978 general aviation fleet of 180,000 registered, active aircraft would produce the following aircraft population:

Single engine aircraft (one-to-three place)	59,400
Single engine aircraft (four-place or more)	90,000
Multiengine aircraft (under 12,500 pounds)	<u>2,220</u>
Total	151,620

There is no method of determining how many of these aircraft presently are or will be equipped with upper torso restraints, nor can it be established how many aircraft do not or would not have structural provisions for shoulder harness attachments. However, an assumption that 10 percent of the fleet is equipped with upper torso restraints, and 40 percent do not have the necessary structural support for restraint attachment, means that 50 percent of the estimated fleet (75,000 plus aircraft) would be affected by proposed regulation to install (i.e., retrofit) upper torso restraints. Whether the percentage estimates are precise does not alter the fact that a major proportion of general aviation aircraft owners would be burdened with the purchase and installation costs of upper torso restraints. Purchase price for a diagonal chest belt and lap belt including the inertia reel system is approximately \$55 per seat. With a variable cost for installation, total costs for a four-place aircraft could run between \$350 and \$500. The opposition to retrofit is strengthened by this cost consideration.

TABLE 2. POPULATION OF REGISTERED GENERAL AVIATION AIRCRAFT BY TYPE

AIRCRAFT TYPE	NUMBER OF AIRCRAFT PER YEAR				
	1969	1970	1971	1972	1973
Single-Engine - One to three place Under 12,500 lbs. 12,501 lbs. and over		44,778 <u>107</u>	59,247 <u>139</u>	60,333 <u>174</u>	49,153 <u>74</u>
Total	45,006	44,885	59,386	60,507	49,227
Single-Engine - Four place and over	63,699	64,758	73,946	75,765	74,847
Multiengine					
Reciprocating engine powered	15,981	15,883	18,576	18,735	18,667
Turbine engine powered	2,229	2,408	1,148	1,148	1,393
Turboprop engine powered			<u>1,557</u>	<u>1,557</u>	<u>1,863</u>
Total	18,210	18,291	21,281	*21,440	*21,923
Rotorcraft					
Under 12,500 lbs. 12,501 lbs. and over		2,180 <u>75</u>	2,937 <u>142</u>	3,274 <u>106</u>	2,872 <u>76</u>
Total	2,557	2,255	3,079	3,380	2,948
Glider	1,435	1,554	1,734	1,785	1,656
Total of types displayed	130,906	131,743	159,426	162,877	150,601

\*Multiengine aircraft under 12,500 lbs. - 18,850; 12,501 lbs. and over - 3073.

Note: 1973 data are latest information available.

If the FAA were to withdraw the proposed requirement for shoulder harness retrofit, another significant problem might arise as indicated by a recent study (reference 23) of attrition in the domestic general aviation fleet (figure A-5 in appendix A). The study shows that with an attrition rate of 3 percent, the majority of the 75,000 general aviation aircraft mentioned in table 2 will be flying 10 or 20 years hence. In view of the described costs, it is likely that they will still be flying without upper torso restraints. Under these circumstances, it is highly improbable that there will be a significant reduction in the number of injuries attributable to head and body impact with the cabin interior in survivable aircraft crashes.

#### RECOMMENDATIONS.

The data substantiate the need for occupant protection in the event of survivable crash accidents. Consideration should be given to regulatory action based on a modified version of NPRM 73-1 to require as a minimum, (a) the installation of upper torso restraints in newly manufactured aircraft, (b) wearing of the installed restraints during the takeoff and landing phases of flight, and (c) the establishment of a reasonable time period for the installation of front seat upper torso restraints in previously manufactured aircraft that have adequate structural provisions for restraint installation. The installed restraints should not restrict crew mobility or egress from the aircraft in an emergency.

On June 9, 1977, Amendment 23-19 to FAR 23 was adopted to require approved belts and shoulder harnesses for front seats and to require that they be worn during takeoff and landing. (For aircraft manufactured after July 18, 1978).

### SEAT LATCHES

#### THE PROBLEM.

The seat latches of various general aviation aircraft do not insure adequate locking in intermediate positions. With the application of power for takeoff, the force exerted on the seat because of aircraft acceleration could cause the seat to slide to its rearmost position, with possible loss of control.

#### RELEVANT FACTORS.

Most late model general aviation aircraft have adjustable pilot and copilot seats. In the simplest form of seat adjustment, the pilot can make a manual adjustment in a fore and aft direction. This is accomplished by depressing a spring-loaded lever or bar, generally located under or on the side of the seat, which retracts a metal rod from one of several circular detents in a fixed track attached to the cabin floor. The seat is then free to move on this track in a fore and aft direction until the pilot releases the lever. The spring-loaded rod is then aligned and inserted into one of the circular

detents that hold the seat in the adjusted position. In addition to fore and aft positions, more complex (but more costly) seat systems allow for manual or powered adjustment of the seat height and seat back position.

The specifications for aircraft seats and berths are defined in National Airworthiness Standard (NAS) 809, prepared by the Airworthiness Requirements Committee (ARC) and in FAR 23.785. These specifications define the minimum performance and safety standards for seats and berths.

The requirements pertain primarily to the structural strength of the seat with no specific reference to seat adjustments or positive action of the seat locking device. FAR 23.785 (c) states: "Each pilot seat must be designed for the reactions resulting from application of pilot forces to the primary flight controls as prescribed in FAR 23.395."

NAS 809 4.1.2.5 states: "The seat or berth in any of its adjustable positions shall be capable of withstanding the limit loads without suffering detrimental permanent deformation. At all loads up to these limit loads, the deformation shall be such as not to interfere with safe operation of the airframe."

Possibly these requirements could be presumed to cover the case of accelerations imposed during the takeoff phase of flight. Under this interpretation, if a seat slips from its adjustment detent position, the regulation should apply; therefore, a seat that lacks positive latching and can slip does not meet present FAR and NAS requirements. If this is the intent of the present regulations it should be made explicit, since not all seat track latches have the required positive lock action.

The pilot survey conducted early in this project indicates that the occurrence of seat slippage is more frequent than realized, and only luck or proper action on the pilot's part has kept this potential accident cause to the low frequency found in the accident data.

Over 50 percent of the pilots interviewed offered critical comments on the adequacy, location, and operation of adjustable seat latching mechanisms. This majority of pilots/flight instructors related seat slippage incidents which they or their students had experienced. Fortunately, none of their occurrences had resulted in an accident.

Pilots stated that because of the large number of slippage incidents, the seat latch mechanism should incorporate a positive lock feature which should be detectable by feel and/or sight. A possible design to accomplish this would consist of a sloped indentation on the front side of each spring loaded hold position and a projecting ridge behind each hold position. The cross-bolt locking lever would then be caught in the next detent position aft of the starting point. There was no specific preference for location of the fore/aft seat adjustment latch other than to standardize the location. In addition, the majority of pilots interviewed expressed the opinion that seat adjustment lever actuation should be standardized, citing the variety of existing systems that require either a push, pull, press or lift motion of the adjustment lever to position the seat.

#### ACCIDENT DATA.

A review of the NTSB accident data for the period 1970-1974 (reference 13) revealed seat slippage as a contributing factor in 26 aircraft accidents, including two that were fatal.

The accident data for seat slippage problems are sparse, and as shown by the pilot survey they do not represent the actual number of seat slippage incidents. The reason for this difference is that this occurrence does not ordinarily result in a reportable accident. An improperly latched seat can cause the seat to slip or slide rearward to a position where the pilot, unable to maintain foot contact with the rudder pedals, may lose directional control of the aircraft.

In the worst accident case studied, seat slippage during the climbout phase of flight resulted in the pilot's seat sliding to its rearmost position at which point the seat back failed. Since the pilot still clung to the yoke, the aircraft pitched up, stalled, and crashed. The pilot sustained fatal injuries, and the aircraft was destroyed.

In another accident involving an airplane flown from the right seat, the investigator's report revealed a hazardous condition of the left seat:

"Moving the left front seat fore and aft showed that when the seat was near full-forward, the upper left corner of the seat bumped against the upholstered doorframe. The seat could only be moved to the most forward, locked position by forcing it.

"Examination of the left front seat showed the upper left side was bent inward. The forward left housing for the seat roller was bent, and the roll pin which locks the seat to the rail was tapered and brightly polished. The holes in the rails were elongated fore and aft. When the seat was pushed forward, the roll pin would not completely enter the hole and secure the seat. When a moderate amount of side or aft pressure was applied, the seat would slide aft to the rear stop.

"Since purchase, the owner had flown the aircraft 23 hours. During this time he noted it was difficult to lock the left seat in place, and at times during flight, the left seat would slide aft without being unlatched. For this reason the pilot decided to fly the charter trip from the right seat."

Although the left seat was not a direct cause of the accident, it is interesting to note that the owner/pilot was well aware of the severity of the condition of the latching mechanism.

#### DISCUSSION.

With frequent adjustment, aircraft seat latches and seat tracks are subject to great wear. Forward seats are positioned and repositioned not only to accommodate pilot size, they are also moved to facilitate the entry and exit of rear seat passengers. The team's inspection of a variety of single engine aircraft at several local airports confirmed the wear of the adjustment hardware.

Although seat locking mechanisms may work in a satisfactory manner during certification tests, a deterioration of the seat latch and track systems through normal use can result in seat slippage accidents and incidents.

The most noticeable deterioration evidenced was that of the seat track. In addition to a deep scoring of the track upper surfaces, the circular detents were elongated. The seat legs of two aircraft were bent, and a sideward force exerted on the seats dislodged the seat leg from the track.

Because of the number of circular detents provided in the seat track to accommodate variations in pilot size and leg length, it should be expected that if the seat locking rod fails to hold in one detent, the seat, sliding rearward, would engage the next detent and hold. However, given a combination of worn detents, bent tracks or seat legs, or weak spring locks and a sufficient forward acceleration, the seat can slide to its rearmost position without engaging any of the detents.

If this does happen, the pilot, caught unaware, can lose physical contact with the yoke, rudder pedals and power controls, or worse, if airborne, experience the pitch up, stall accident mentioned previously.

It is much easier to examine the seat tracks, detents, and supporting seat structures of high wing aircraft than those of low wing aircraft. The pilot has the advantage of standing outside the aircraft and getting a clear view of these structures. The provision of doors on both sides of the aircraft makes the inspection task that much easier. However, in neither the high nor the low wing aircraft does the pilot have the capability of examining the condition of the spring loaded rod ends that snap into the detents, since that part of the rods is completely obscured by the seat roller guide assembly. To inspect the retractable rod end for wear, malformation, or fracture requires the complete disengagement and removal of the seat from the tracks. Needless to say, none of the pilots interviewed went to this extent in preflighting an aircraft. A few pilots said they made routine checks of the detents to insure that there was no accumulation of dirt. Most pilots said they relied on the preflight technique of exerting back pressure against the seat once it had been adjusted to its desired position.

With but one exception, no innovative design changes to seat latch or locking mechanisms were noted during the team inspection of current production aircraft. The exception was one manufacturer's installation of an adjustable metal stop or limiter for seat travel as part of the double seat track, with both tracks lockable rather than only one as in earlier aircraft. With this new design, if the seat slips back from its positioned detent, the stop prevents the seat from sliding to its rearmost position. The chief engineer said that should the seat slip backward, the pilot might lose contact with the rudder pedals, but the stop still would allow him access to the yoke and power controls. Furthermore, the use of twin locking tracks makes even this degree of slip unlikely.

This and similar designs for cockpit components enhance aircraft safety, and exceed the minimum certification requirements. But it is disturbing that under some possible interpretations, there are no minimum FAR requirements for seat latches and locking mechanisms.

A proposal, ARP 1318, for General Aviation Seat Design is contained in appendix B. The document, "Cockpit/Cabin Standardization; General Aviation Aircraft," was prepared and approved by the SAE Committee A-23, on October 21, 1975. The ARP recommends adjustable seats with provisions for vertical, angular, and fore and aft seat adjustment. The proposal recommends that the fore and aft seat-adjusting mechanism be designed to insure against inadvertent actuation, either by the occupant or by inertia forces to extreme fore or aft positions during normal or emergency flight conditions. The ARP also recommends a standard location of the seat actuation control.

The proposed recommendations of ARP 1318, in conjunction with the accident data and pilot comments on seat slippage incidents, attest to the fact that inadvertent seat slippage is a potential cause of aircraft accidents. The proposed recommendations are most relevant and worthy of consideration for a more concise definition of seat and berth requirements. As mentioned previously, SAE ARP's are advisory only, and their use by anyone engaged in industry or trade is voluntary. The SAE terminated the A-23 Committee before a final approved version of ARP 1318 could be published. The document is not listed in the August 1976 numerical index of current, new, and revised ARP's.

#### RECOMMENDATIONS.

Adjustable seats should be required to have a positive seat locking device to prevent the seat from inadvertently slipping from its adjusted position. The pin in or "lock" position of the adjusting lever should be clearly different from the unlocked or "adjust" position, so that the pilot can tell by sight and feel whether or not the seat is locked or secured in the detent. In any event, the seat should not be able to suddenly move to an extreme position from which the pilot can not reach the power or flight controls.

### DOOR HANDLES AND LATCHING/LOCKING MECHANISMS

#### THE PROBLEM.

General aviation aircraft accidents have occurred because the aircraft cabin door opened in flight. The causes have been attributed to: (1) pilot failure to insure that the door was secured properly, either through neglect or unfamiliarity with the door latching mechanism, (2) a type of door latch which precludes a visual check that the door is properly closed and locked, and/or (3) a latching/locking mechanism defective or worn from normal use, which fails to hold the door locked under conditions of airloads, turbulence, or vibration.



## RELEVANT FACTORS.

The inflight door opening, while not catastrophic in itself, can create a stress situation for the pilot. While concentrating on the problem of the open door, he/she may fail to maintain flying speed and stall or lose control of the aircraft. The literature and accident data on inflight door openings, as in seat slippage accidents, are sparse. Information which is available shows that many accidents involving inflight door opening occurred when the pilot either attempted a panic abort of the takeoff, or, if already airborne, made a precipitous return to the airfield. In the first type, the aborted takeoff either resulted in the aircraft overrunning the runway, or because of heavy braking, a tire failed and the aircraft ground-looped or swerved off the runway. In the other type, pilots overly anxious to make a precautionary landing forgot to lower the landing gear or made a poor approach/landing and swerved off the runway with resultant damage to the aircraft.

Newer aircraft owner's manuals list the item "Doors and Windows-Lock" in the before takeoff checklist, but a study of older manuals, 1967 to 1972, disclosed a lack of information pertaining to normal door locking procedures or emergency procedures to contend with a door opening in flight. In contrast with approved airplane flight manuals, the information contained in aircraft owners manuals is not FAA approved (FAR 23.1581, reference 1).

The following information was provided in a 1967 owners manual under "Emergency Procedures."

"Unlatched Door in Flight. If the cabin door is not locked, it may come unlatched in flight. This usually occurs during or just after takeoff. The door will trail in a position approximately 3 inches open, but the flight characteristics of the airplane will not be affected. Return to the field in a normal manner. If practicable, during the landing flareout have a passenger hold the door to prevent it from swinging open.

In an emergency, it is possible to close the door in flight as follows:

1. Slow to approximately 90 mph (78 knots) indicated air speed (IAS).
2. Open the storm window to reduce cabin air pressure.
3. Bank steeply to the right.
4. Simultaneously apply left rudder (which will result in a slipping maneuver) and reach over and close the door.

In 1975, GAMA representatives published a draft specification for use in preparing pilots' operating handbooks (POH). The specification provides broad guidelines for preparing handbooks for all types of general aviation aircraft, excluding jets, under 12,500 pounds. There is no doubt that the specification is a major achievement in industry standardization of pilot handbooks, and it

is a document which provides the aircraft owner excellent operational information in useful form. The draft specification for POH's has a section of the text devoted to "Description and Operation of the Airplane and its Systems" and includes:

"Doors, Windows, and Exits.

1. Describe how to operate and lock doors, windows, and exits.
2. Explain any procedures or warnings necessary for the doors, exits, windows, or windshield wipers.
3. Discuss how to close a door or window if it opens accidentally in flight and any restrictions there may be on purposely opening in flight.
4. Give precise instructions for using emergency exits."

This type of information, much of which was not available in older aircraft manuals, can enhance the pilot's knowledge of his aircraft systems and equipment. The knowledge of how to cope with the open door situation can alleviate the initial stress accompanying this type of emergency, and could make the difference between a safe precautionary landing and one which results in an accident.

Nevertheless, the excellent and expanded information provided by GAMA's revised pilot operating handbooks is not the complete answer. The information supplied recognizes that doors can open in flight, either because of pilot fallibility or equipment problems. The procedure to correct the situation then becomes an "after the fact" solution.

The variety of aircraft door handles, shapes, location, door latching mechanisms, and methods of actuation, coupled with the minimal requirements for doors specified in FAR 23.783, emphasizes the need for standardization and design improvements to minimize, if not completely eliminate, the inflight open door problem.

ACCIDENT DATA.

Fifty-nine of 82 (72 percent) of the pilots interviewed by the project team commented on the lack of standardization of general aviation aircraft door latching/locking mechanisms. At one time or another, these pilots experienced door openings in flight. Pilots cited lack of standardization in the logic of latching/locking operation, the inadequacy of the latching/locking mechanism, and the lack of a visual indication to confirm that the cabin door is locked.

The number of aircraft accidents in which inadvertent inflight door opening is a contributing factor is not representative of the actual number of open door incidents. In many cases, as attested to by the pilots and instructors interviewed, the pilot performs successfully the necessary procedures to get the door closed and continues the flight, or lands safely. Other than

the pilot sampling and interview technique employed in this project, there is no method by which one can determine the actual number of inflight door openings which do not result in accidents or incidents.

An NTSB survey (reference 24) of the 7-year period between 1968 and 1974 disclosed that 63 inflight door openings caused 38 precautionary landings and that door opening was a contributing factor in 7 fatal accidents in which 19 people were killed. The accident data revealed that an average of at least five accidents per year (1970 to 1974) were related to inflight door openings.

Two examples of inflight door accidents follow.

The pilot, owner of a newly purchased aircraft, planned a local visual flight rules (VFR) flight. Preflight and runup were normal, but just as the aircraft became airborne, its door popped open. The pilot, a veteran of 1,000 hours in type, elected to return to the airfield, land and correct the problem. However, while turning on to final approach, the aircraft apparently stalled and fell 50 feet. It struck the ground 200 feet short of the runway, hit a 15 foot high tree, its left wing dug into the sand, then the right wing struck the ground. The plane ground looped and skidded another 100 feet. The aircraft was a total loss (reference 25).

The pilot was enroute to his destination and approaching the airfield when the cabin door opened. Because of excessive vibration, the pilot thought that, in addition to the open door, he was having engine problems. He shut down one engine but the vibration continued. The pilot attempted to gain altitude, but with the excessive noise and vibration, he was concerned that he might stall the aircraft. The pilot stated he could not maintain level flight and keep up his airspeed. His attempt to reach the airport runway failed (reference 26).

Both pilots had over 1,000 hours in type, which implies they were well acquainted with the equipment, systems, and features of their aircraft.

#### DISCUSSION.

Recommendations for new door handle, latch, and locking system designs are not within the scope of this study. The design features discussed will provide the reader with an appreciation of the variety of handle, latch, and locking mechanisms in current general aviation aircraft, and how they may be related to the inflight open door problem. (The latching mechanism prevents the cabin door from opening when closed and latched. The locking mechanism generally prevents the inadvertent opening of the latching mechanism.)

Design improvements over the years have included placement of the door handle, in its locked position, in such a manner as to preclude inadvertent opening of the door through arm, elbow, or body contact of the pilot or passenger. Close-lock or backup lock systems are similar to those found in automobiles. These systems feature a door handle to close the door with a separately placed push-pull button or rotating lever to lock the door. Also, the dual function

system may be incorporated solely in the handle, with some form of rotational action to close the door, and an extra pivotal action to lock it. The design philosophy is that, in the event the cabin door becomes unlatched in flight, the secondary lock feature will prevent it from fully opening. Another design change has been the provision for door handle insets, making the handle flush with the door interior to eliminate the handle projection as an injurious object in the event of a minor crash landing, and to inhibit inadvertent opening by an occupant's clothing. Some of the older rotatable automobile type handles have been replaced with a large square or rectangular metal tab that is flush with the door interior. As a rule, this type of door handle is pulled in toward the cabin interior to open the door. The result is not to physically move the door, but simply to retract the latch mechanism from its holder so that the door can open. In addition to this type of action, there are variations on clockwise and counterclockwise handle motions either to shut or to open cabin doors.

The prevailing design for door latches is that of a straight rod or beveled bolt (tongue or tenon), similar to that found in common household doors. The action of the door handle is to retract or deploy the tenon from or into the bolt holder (mortise). This simplified system latches but does not lock the cabin door, and is a common system in the general aviation fleet.

Locking systems generally function by one of three methods:

1. The tenon itself is locked and immovable in the mortise. This type is found in the dual purpose close-lock door handle.
2. The door handle is made inoperative by a separate lock. The automobile pushdown button lock exemplifies this type of locking mechanism.
3. A separate locking latch may lock the door but neither immobilizes the tenon nor renders the door handle inoperative. Such a latch usually hooks onto a heavy duty metal staple accessory.

If the door is not closed or latched properly, i.e., with the tenon positioned securely within the mortise, the locking mechanism for methods 1 and 2 typically is ineffective and a hazardous situation may exist when the aircraft is airborne.

Project team examination of three manufacturers' production aircraft disclosed several innovations in cabin door hardware. With minor exceptions, the modified design features verify the manufacturers' awareness of the inflight open door problem, and their endeavors to minimize that type of occurrence.

Some of the features noted were double latching points in the cabin door, dual action door handles, e.g., push-button and turn handle, and dual function door handles which incorporate a close-lock capability. Locations of door handles, types of handle action, and locking mechanisms vary from one aircraft manufacturer to another. However, taking into consideration the constraints imposed by the aircraft door assembly, each manufacturer seems to have attempted

a standardization of door hardware within the particular line or model of aircraft. For example, one aircraft company employs the same type of door handle, handle action, location, and locking mechanism in the majority of its aircraft models. An exception to this standardization, pointed out by the chief engineer, was on its smallest aircraft, where the thickness of the door was not sufficient to house the otherwise standard door handle assembly. Using the standard assembly would necessitate making each door one-half inch thicker with a resultant one inch decrease in the interior cabin width.

It would be ideal if all handles, handle action, and locking mechanisms were consistent across the spectrum of general aviation aircraft. This, of course, is difficult given the multitude of different model aircraft. Regardless of the variety of door handles, latches, and locking mechanisms, what is needed is a positive identification by the pilot that the door is indeed closed and locked.

No organized data were available which isolated specific reasons for cabin doors opening in flight. A review of the accident records revealed pilot failure to check the cabin door security or faulty lock/latch mechanisms as causes for the door opening. Pilot statements described how they had closed the cabin door but neglected to check its security. It is common practice for pilots to push against the cabin door or, if occupying the right seat as a flight instructor, push heavily with their shoulder against the door to insure door security. Making use of this technique underscores the fact that the pilot has no visual means to assure that, having closed the door, it is positively closed and locked.

Project team members used the shoulder-against-the-door technique in the examination of various light aircraft. Cabin doors were closed and appeared to be locked. But in two aircraft, the application of shoulder pressure against the doors produced occasional openings. Company personnel explained that the occurrence might be attributed to the newness of the aircraft, i.e., a tight door seal. Notwithstanding this explanation, the fact remains that a visual check alone for door security was not adequate.

The regulation governing doors for transport category aircraft is FAR 25.783 (reference 27). The regulation requires a means to lock and safeguard doors against opening in flight. The means of opening must be simple, obvious, and readily located and operated. There must be a provision for direct visual inspection of the locking mechanism to insure that the door is locked. Also, each external door must be capable of being opened from both the inside and outside. This last requirement was not considered previously by the team, but its importance for Part 23 aircraft was stressed by an accident investigator from a General Aviation District Office. He stated that locked doors of many current general aircraft cannot be opened from the outside causing a perilous situation if the occupants, because of injuries, are unable to open the cabin doors from the inside and rescuers are unable to open the door(s) from the outside.

## RECOMMENDATIONS.

Consideration should be given to regulatory or other design practice action to require positive door latch/locking mechanisms. Means should be provided to allow direct visual inspection to insure door security, and/or preclude locking of a door that is closed but not securely latched. It should be possible to open the door from the outside.

## FUEL MANAGEMENT

### THE PROBLEM.

A survey of current FAR 23 aircraft revealed a marked lack of standardization in fuel systems. NTSB reports document fuel system mismanagement by the pilot as a major cause of accidents with both fuel starvation and fuel exhaustion being frequent findings of cause. The present nonstandard fuel systems, consisting of the tank selector control, its associated marking, and the fuel quantity indicators, do not provide optimum protection against pilot error.

### RELEVANT FACTORS.

Seventy-two percent of the pilots and flight instructors interviewed during this study commented adversely on the nonstandard fuel systems and components that are prevalent in today's general aviation fleet. Those comments were directed specifically to the fuel selector control--its location, accessibility, markings, construction, and operation logic--and the fuel quantity indicators--location, accuracy, legibility, and markings.

Subsequent to the data collection phase, the team conducted field inspections of a variety of general aviation aircraft manufactured since 1968 and confirmed the reported lack of standardization of fuel systems.

### ACCIDENT DATA.

A study by the NTSB of accidents involving engine failure/malfunction for the years 1965 through 1969 revealed the pilot in command as a probable cause or a related factor in 52 percent of the engine failure accidents, with mismanagement of fuel cited as a predominant factor (reference 28). Mismanagement of fuel, by NTSB definition, is any act of omission or commission by the pilot, with reference to fuel or the fuel system, considered causative in the accident.

The study showed that 19.3 percent of 4,310 engine failure accidents had been caused by fuel starvation. Fuel starvation is defined as the interruption, reduction, or complete termination of fuel flow to the engine although ample fuel for normal operation is available aboard the aircraft.

NTSB conducted a second special study (reference 29) concerning accidents related to engine failure/malfunction and fuel starvation, and the results of these studies led to the formation of the Fuel System Standardization Committee by GAMA. Working closely with the FAA and NTSB, the committee's objectives were to standardize, where possible, and simplify future aircraft fuel systems. This action culminated in a draft document which proposed changes to FAR 23.777 through 23.781, and suggested standardized limits and nomenclature for fuel selector valves and other components of aircraft fuel systems. The draft proposal and related documentation are contained in appendix C.

This second special study was conducted by the NTSB to: identify the most frequent causes of fuel starvation accidents, examine factors involved, and propose remedial action to reduce the number of fuel starvation accidents. An AOPA analysis of the report (reference 29) is shown as appendix D. It concluded:

"While 87 percent of the fuel starvation accidents were attributed to operational problems, the problems were not independent of the factors which influenced or caused them." Design associated factors cited were:

1. Owner manuals which often lack detailed information on fuel management and fuel system purging operations.
2. Fuel systems which require tank switching in order to manage the fuel supply properly.
3. Fuel selector valves with handle design, mode of operation, or tank display which may be conducive to mispositioning.
4. Placement of engine controls and similarity of appearance which may be conducive to improper use.

A NAFEC review of NTSB general aviation accident data for the years 1970-1974 (reference 13) showed its similarity to data reported previously for the years 1965 through 1969. The 1970-1974 accident data revealed 4,954 engine failure/malfunction accidents including 1,255 attributable to fuel mismanagement. Of these accidents, 832 were caused by fuel starvation, including 31 accidents in which the fuel selector valve was positioned between tanks, a design-associated factor mentioned in the NTSB report. The 4,954 accidents consisted of 386 fatal, 593 serious, and 1,072 minor injury accidents with 959 aircraft destroyed, and 3,990 substantially damaged.

#### DISCUSSION.

FAR 23.777(f) states: "Each fuel feed selector control must be located and arranged so that the pilot can see and reach it without moving any seat or primary flight control when his seat is at any position in which it can be placed."

It is reasonable to interpret this requirement as meaning that the location must be such as to permit convenient operation by either pilot in a dual-control aircraft, since the pilot may be seated in either control position. In an

emergency or in a training situation, the right seat pilot in a side-by-side arrangement may need to operate any vital cockpit control. In a few aircraft models, one such control that presently is inaccessible to the instructor/copilot is the fuel selector.

Unfortunately, FAR 23.777(f) has been interpreted in the certification process to allow mounting the fuel selector control on a cockpit sidewall. Generally, such side mounted selectors do not conform to what is considered good human engineering practice, in that they do not preserve natural relations. Mounted on the side, for example, the pointer does not point to the right when the right wing tank is selected. Furthermore, FAR 23.995(a) states that there must be a means to allow flight crew members to rapidly shut off, in flight, the fuel to each engine individually, and (b) that there must be a means to guard against inadvertent operation of each shutoff valve.

FAR 23.1337(f) "Powerplant Instruments" requires a means to indicate fuel quantity. Unfortunately, there is a marked lack of standardization in the systems that are used. Some aircraft have one gauge for each tank, while others share one gauge for several tanks and provide a switch so that the pilot may obtain a reading on the level of each tank in turn. Still other aircraft have a fixed relation between the fuel tank selector control and the fuel gauge selector control whereby it is necessary to switch fuel flow to a particular tank to obtain an indication of the amount of fuel remaining in that tank. This diversity can cause misunderstanding. A fuel system diagram posted adjacent to the selector control would minimize confusion of fuel tank usage. General simplification of the fuel system should be encouraged.

In 1968, a study (reference 30) was conducted at NAFEC to design a fuel selector control that conformed with good human engineering practice. It recommended: (a) the selector handle should be the pointer to prevent misreading of the selection, (b) that natural relations be used in pointer directions, e.g., right for right tank, forward for all tanks, rear for shutoff, etc., (c) that the OFF position be at least 90° away from any tank selection position, and (d) that in dual control aircraft, both pilots have easy access to all fuel controls.

The GAMA fuel valve selector control committee proposed design guidance additions (appendix C) to the present regulations for FAR 23 aircraft. They include:

"Operating motion of the handle shall be to the right for right hand tanks, to the left for left hand tanks, and extreme left or aft for OFF. All other tank selections shall be between left and right tank position, except for the crossfeed position on individual engine selector valves on multiengine aircraft which shall be to the extreme right or forward.

The indication as to the fuel valve position selected shall be by means of a pointer and shall provide a positive identification of the position selected.

The position indicator pointer shall constitute or be located on the maximum dimension portion of the handle measured from the center of rotation.



The emergency shut-off valve handle shall be red. If the fuel selector valve handle is also a fuel shut-off handle, the OFF position marking shall be red.

Fuel selector valve position placards shall be immediately adjacent to the indicator end of the selector."

These additions are compatible with the recommendations of the NAFEC study with the exception that the GAMA committee proposed no change to FAR 23.777 regarding location of the fuel selector control. The NAFEC recommendation for equal access by both pilots in dual-control aircraft is supported by the fact that many dual-control aircraft manufactured today are side-by-side layouts with fuel stored in the wings and have the fuel selector control near the midline where it is equally distant from the right and left tanks, and visible to and accessible by both pilots. But certain products of one large manufacturer have the control located on the left sidewall where it might be difficult for the copilot or instructor to see the selection or to reach it in an emergency. No compelling structural or economic reason was uncovered to rule out requiring relocation near the midline in new production airplanes. Hence, it is feasible to add the equal access requirement to the GAMA proposal.

During the survey phase of this effort, many pilots and operators reported that the accuracy of fuel quantity gauges was a problem. As required by FAR 23.1337(b)1(1), each fuel quantity indicator must be calibrated to read zero during level flight when the quantity of fuel remaining in the tank is equal to the unusable fuel supply. Apparently the fuel gauges become inaccurate over the service life of the aircraft and are not readily correctible. This could trap the unwary pilot who may not have planned sufficiently his fuel consumption and fuel reserves.

A further addition to the GAMA proposal should be a requirement for accuracy of fuel quantity gauges when such indicators are provided. Since the great majority of new aircraft do have fuel gauges, and these gauges are thought to be accurate when new, it is suggested that a quality standard should be added to insure that the gauges retain their accuracy over time. The shape and production tolerances of tanks and the fuel motion effects prevent absolute accuracy, but it is within the state-of-the-art to provide gauges that are reasonably accurate and that can be serviced as required to preserve that accuracy.

#### RECOMMENDATION.

It is recommended that consideration be given to implementing the GAMA proposal for FAR 23 fuel system standardization with the additions that the fuel tank selector handle must not pass through the OFF position when switching from one tank to another and should be accessible to both pilots in a side-by-side aircraft. Consideration should also be given to the adoption of a quality standard for fuel gauge accuracy.

## POWERPLANT CONTROLS

### THE PROBLEM

A significant number of accidents has been caused by improper operation of the powerplant controls. The cause is attributed to pilots moving a wrong lever or power control. A contributing factor is the variation of control location and arrangement existing in FAR 23 aircraft.

### RELEVANT FACTORS.

Inspections of general aviation aircraft disclosed a lack of standardization in the location, operation, and arrangement of powerplant controls. The NTSB has identified the variability of control location and arrangement as a contributing factor in a significant number of engine failure accidents (reference 29).

The lack of control standardization, which contributes to pilot error accidents, has been reported and discussed for the past 30 years, but only within the past 10 years has there been a conscientious effort (primarily through the implementation of recommended design practices rather than regulatory action) to apply proven human engineering design concepts to powerplant controls in general aviation aircraft. Selection of the proper control is a matter of pilot training. Control location, identification, arrangement, and direction of motion are a matter of design.

In an analysis of 460 actual pilot errors in operation of controls, Fitts and Jones (reference 31) identified six basic types of error. In one, the "substitution" type, the wrong control was operated, and constituted exactly 50 percent of all the errors identified. The most common subtypes of errors under that general category were confusion of throttle quadrant controls, confusion of flap and landing gear controls, and using the wrong engine controls or feathering button.

The investigative efforts and results of powerplant control studies by the military, SAE committees, FAA, and others, are numerous. It is very clear that they show a commonality of results summarized by the following excerpt from the Aeronautical Engineering Review (reference 32).

"Control location and coding... There are two effective and practical means of eliminating control confusion: shape coding of critical knobs to permit tactual discrimination and standardization of location of control. By the latter is meant not rigid dimensional standardization, but rather that a given control always be in the same area, and that controls be in the same position relative to each other. In tests using typical throttle quadrant controls, Weitz (reference 33) definitely demonstrated the value of both of these measures...it was concluded that maintaining position of controls is of primary importance, yet if the position is changed and the shape of the handle remains constant, little loss in performance is encountered. The most efficient procedure is to maintain both position and shape constant."

FAR 25.781 specifies the general shapes for the flap, landing gear, supercharger, throttle, RPM, and mixture control knobs. Some provision for control arrangement is specified in FAR 25.1149(d), which requires the propeller speed and pitch controls to be to the right of, and at least 1 inch below, the throttle controls.

While there is no requirement for a specific shape or arrangement of powerplant controls with relation to each other, FAR 23.1147 "Mixture Controls" states in part that: "...each mixture control must have guards or must be shaped or arranged to prevent confusion by feel with other controls."

The regulations, as written, allow for considerable flexibility in the location and arrangement of powerplant controls. On the basis of general aviation accidents attributed to improper operation of the powerplant controls, standardization would prove effective in reducing this type of accident.

More than 50 percent of the pilot and flight instructors interviewed related their own, or student experiences of control confusion/misuse attributable to inconsistencies in powerplant arrangement, location, and activation (table A-2 of appendix A).

#### ACCIDENT DATA.

The NTSB accident data for the years 1970 through 1974 (table 1) show 4,954 engine failure accidents. Of this number, 683 (13 percent) were caused by improper operation of the powerplant controls. A summary report of general aviation accidents for the years 1973 and 1974 (reference 34) shows 167 accidents caused by misuse or failure to use carburetor heat, and 43 accidents attributed to misuse of the mixture control. Some examples of mixture control misuse are depicted in table A-6 of appendix A.

A review of NTSB accident data for improper use of powerplant controls (reference 28) indicates that the most common errors were: (1) pilots inadvertently pulling back the mixture control instead of the carburetor heat control, (2) pilots pulling back the mixture control instead of the propeller control, and (3) retarding propeller RPM control instead of the throttle. The first two pilot error actions can result in the complete cut-off of fuel to the engine with subsequent engine failure. The last action results in reduced propeller RPM with ensuing power loss. If the pilot fails to recognize the improper use of the powerplant controls, or does not have sufficient time or altitude to restart the engine, he is faced with a second type of accident situation, the first being engine failure due to powerplant control misuse. (Note: For an engine failure to be classified as an accident, the occurrence must be in combination with another or second-type accident.) The possible consequences of inadvertent, self-induced engine failure resulting in second-type accidents are depicted in figure 4. The data are for all general aviation operations for the years 1965 through 1969, and show the frequency and percent of accidents resulting in fatal or serious injury occurring from a second-type accident. The self-induced engine failure accident is neither isolated nor limited to the inexperienced pilot. The fact that it does occur with a low but regular frequency indicates the need for an amplification of powerplant control design standardization.

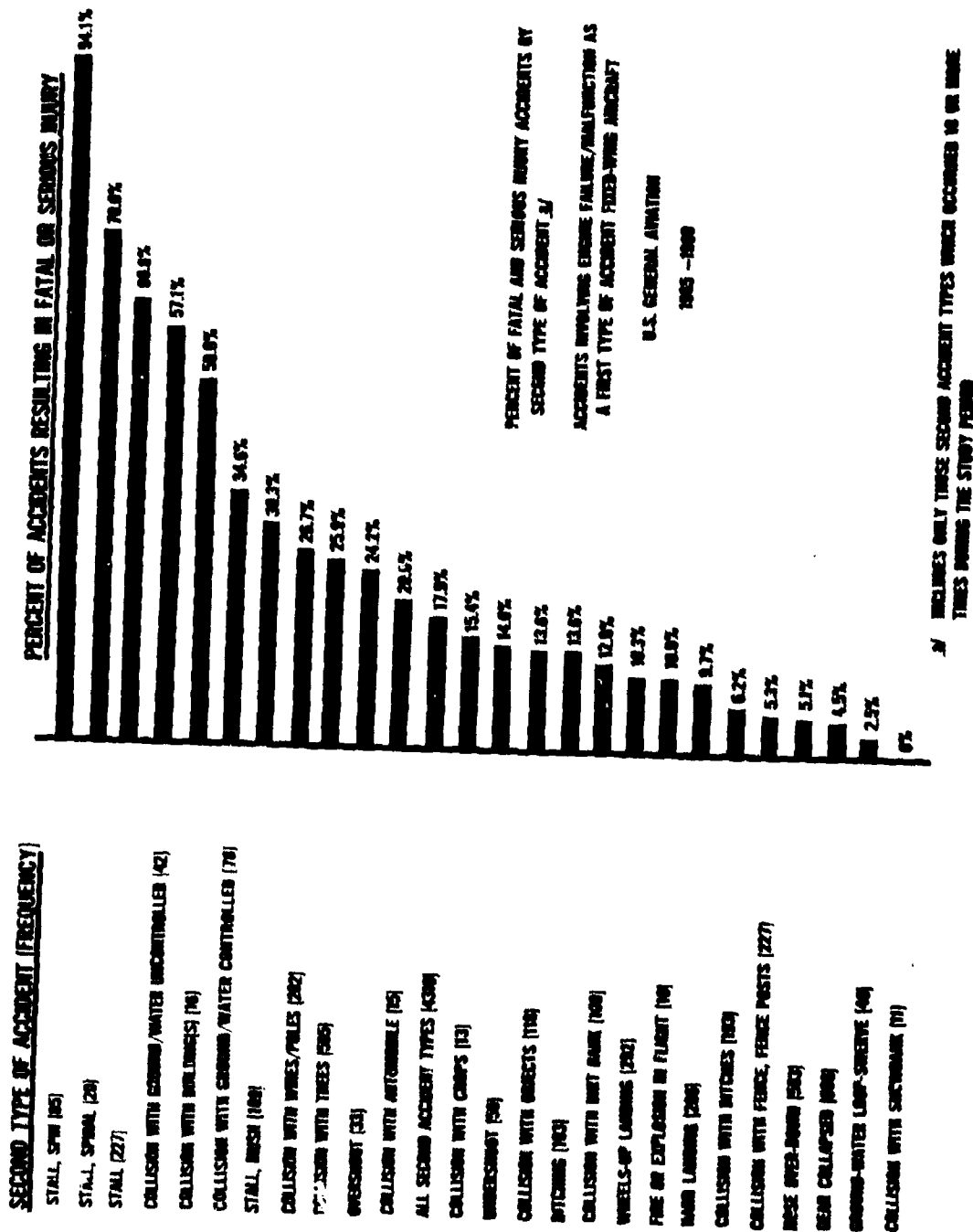


FIGURE 4. FREQUENCY OF SECOND-TYPE ACCIDENTS AS A RESULT OF ENGINE FAILURE

## DISCUSSION.

The location and arrangement of powerplant controls with relation to each other varies among aircraft manufacturers and also within the group of aircraft produced by a single manufacturer. This variability exists in many current production aircraft because the aircraft can be, and are being, manufactured under type certificates that date back 20 years or more.

An inspection of current production aircraft verified the lack of standardization of powerplant controls. In addition to varied placement of throttle, propeller, and mixture controls, there were also variations in the shape and color coding. The carburetor heat controls varied in location and direction of actuation. One of the most accident prone arrangements of the carburetor heat control is one in which the control is located close to the mixture control. If there is no discriminatory shape and/or color coding of these two controls, it is easy to confuse them.

Some manufacturers have adhered to what appears to be the last drafted ARP relevant to controls, prepared by the SAE Committee in 1970, entitled, "Proposed ARP on Location and Actuation of Aircraft Cockpit Controls for General Aviation Aircraft." (A similar document, ARP 268C applicable to FAR 25 aircraft, was issued in 1952, revised in 1962, and in essence constitutes the requirements for FAR 25, aircraft controls.) The ARP for general aviation aircraft proposed a sequential arrangement from left to right, of the throttle, propeller, and mixture control as the pilot in the front seat views the controls. The ARP also recommended locating the carburetor heat control to the left of the throttle or, as a secondary preference, locating it beneath the throttle if the lack of panel space precludes the first arrangement. In either event, the carburetor heat control was not to be located adjacent to the fuel mixture control. It was observed that several manufacturers have incorporated a special safety feature in the design of the powerplant controls, especially the mixture control. The feature incorporates a two-action operation, (push button, retard lever) for movement of the mixture control. The design, while not new, and generally found only in higher priced aircraft, was found occasionally installed in smaller, lower-priced single-engine aircraft. This design inhibits unintentional activation of the mixture control and is one which goes beyond present FAR 23 requirements and SAE/ARP proposals.

Since the SAE Committee A-23 was terminated in 1976, the proposed ARP was never approved or formally published. The basic recommendations, however, have not been ignored. In addition to the work accomplished by the GAMA committees on standardizing specification, nomenclature, aircraft information in the POH and fuel management, they have submitted to the FAA proposed revisions to FAR 23.777 through 23.781 which, fundamentally, are structured on the original SAE/ARP (appendix C).

The GAMA proposal does much to alleviate cockpit control standardization problems recognized and reported by pilots and numerous research organizations over the past years.

GAMA's proposed revisions applicable to powerplant controls are consistent with pilot comments, data, and supplementary information documented in this

study. The project team encountered no substantial evidence or information to support specific color coding of powerplant controls other than an expressed preference by all pilots to have the mixture control color-coded red.

#### RECOMMENDATION.

It is recommended that consideration be given to regulatory action to standardize the arrangement, location, actuation, and shape of powerplant controls as proposed by the GAMA (appendix C). It is further recommended that the mixture control be color-coded red.

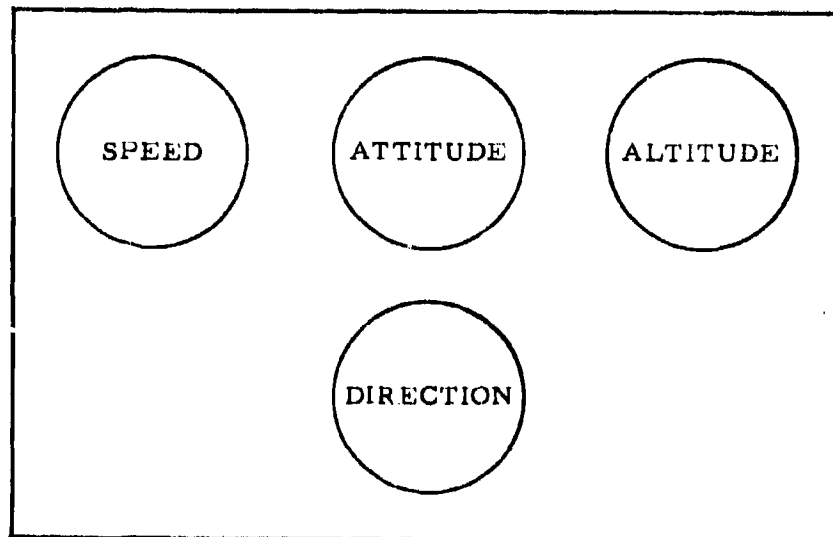
### FLIGHT INSTRUMENTS

#### THE PROBLEM.

FAR 25.1321 and 23.1321 establish the location and arrangement of flight instruments on the instrument panel respectively for transport and normal/utility category aircraft weighing over 6,000 pounds. There is no equivalent regulation to govern the arrangement and location of flight instruments for FAR 23 aircraft weighing 6,000 pounds or less.

#### RELEVANT FACTORS.

Aircraft that have a maximum weight of 6,000 pounds or less are not required to have a standard arrangement of flight instruments on the instrument panel. For FAR 23 aircraft over 6,000 pounds, the four flight instruments which provide basic information on airspeed, attitude, altitude, and direction must be arranged as shown in figure 5 (FAR 23.1321, reference 1).



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FIGURE 5. BASIC T FLIGHT INSTRUMENT PANEL ARRANGEMENT

The regulation for FAR 25 transport category aircraft is essentially the same. The arrangement of these four flight instruments results in the so called "Basic T" panel configuration, and has been a requirement for transport category aircraft since 1957. An identical instrument grouping was made a requirement for FAR 23 aircraft over 6,000 pounds in 1973.

The 1949 and 1950 studies of pilot eye movement by Fitts, Jones, and Milton (reference 35) and the advent of integrated flight instruments i.e., the flight director (FD) and the horizontal situation indicator (HSI), provided the impetus for a reassessment of flight instrument arrangements on the panels of transport category aircraft.

Prior to 1957, flight instrument arrangement for CAR 4b/FAR 25 aircraft was based on an SAE AS which recommended four "standard" arrangements of six flight and navigation instruments commonly referred to as the "Basic Six."

In 1956, the Airline Pilots Association (ALPA) Cockpit Standardization Committee, reporting on a newly-configured T arrangement, concluded, "...that in contrast to the standard Basic Six instrument arrangement, the T arrangement eliminated the need for wide area scanning since all vital information was concentrated in the smallest practicable visual field and centered on the controlling attitude instrument. By employing the T arrangement, eye scan was reduced to less than half that required by the Basic Six arrangement. The Basic T arrangement evolved only after many years of research, development and regulation. Cockpit instrument standardization was becoming widely recognized as a means of reducing pilot workload and increasing the pilot's capacity to deal with other problems and activities associated with flying, navigating, and communicating in the increasingly complex air traffic control system."

In 1965, NAFEC instrument flight pilot workload study (reference 36) revealed that the variations in panel arrangements were random and numerous. Examples of the diverse instrument layouts typical of that period are shown in figures 6, 7, and 8.

In a paper concerning cockpit design and safety, Stieglitz (reference 37) reported: "...the airplane has greater speed, range, and endurance, and operates at higher altitudes. Further, higher wing loading has resulted in a larger maneuvering radius. As a result, the pilot has less time to make decisions and must be more accurate because of the decreased margin for error; if a mistake is made there is little time to correct it. ...the improved performance described above coupled with more complex functional systems has resulted in a greatly increased amount of instrumentation, not only flight and engine instruments but also navigation and electronic equipment. Thus, the pilot is being provided with more information, from more sources...which must be recognized, analyzed, and correlated. In addition, the number of controls in the cockpit has increased correspondingly...therefore, both the increased amount of instrumentation and the greater number of controls tends to increase the amount of time required for the pilot to assess a situation and take necessary action. The combined result has been that greater precision is

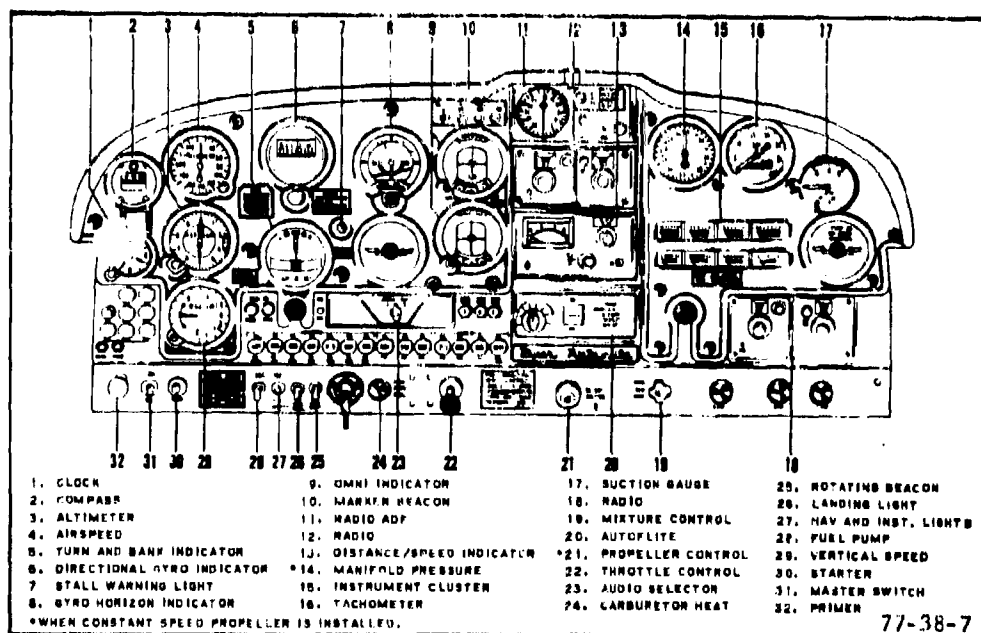
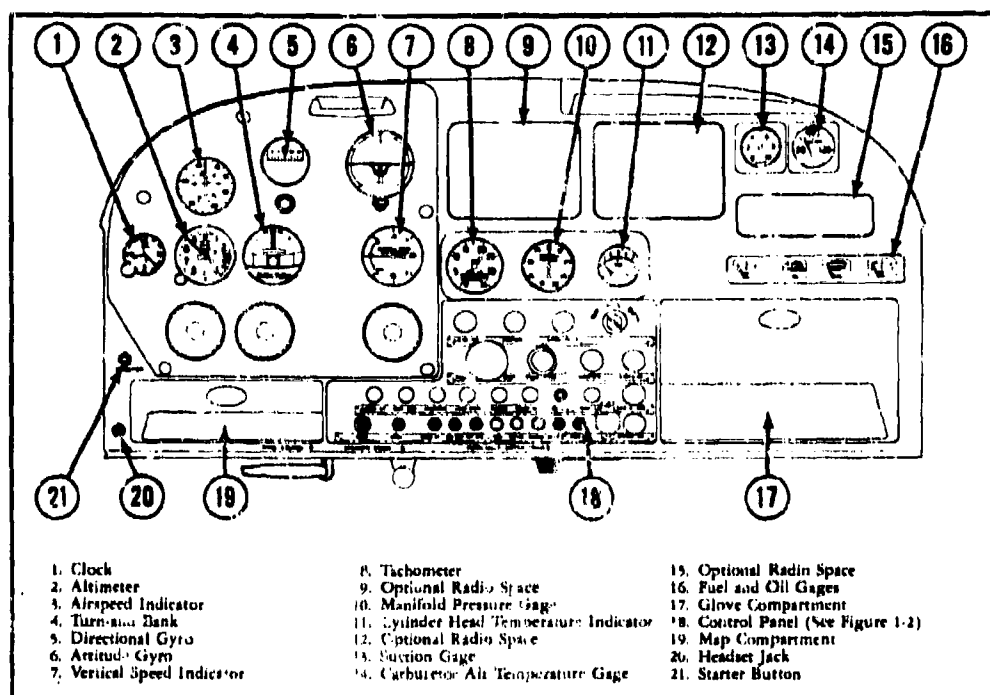
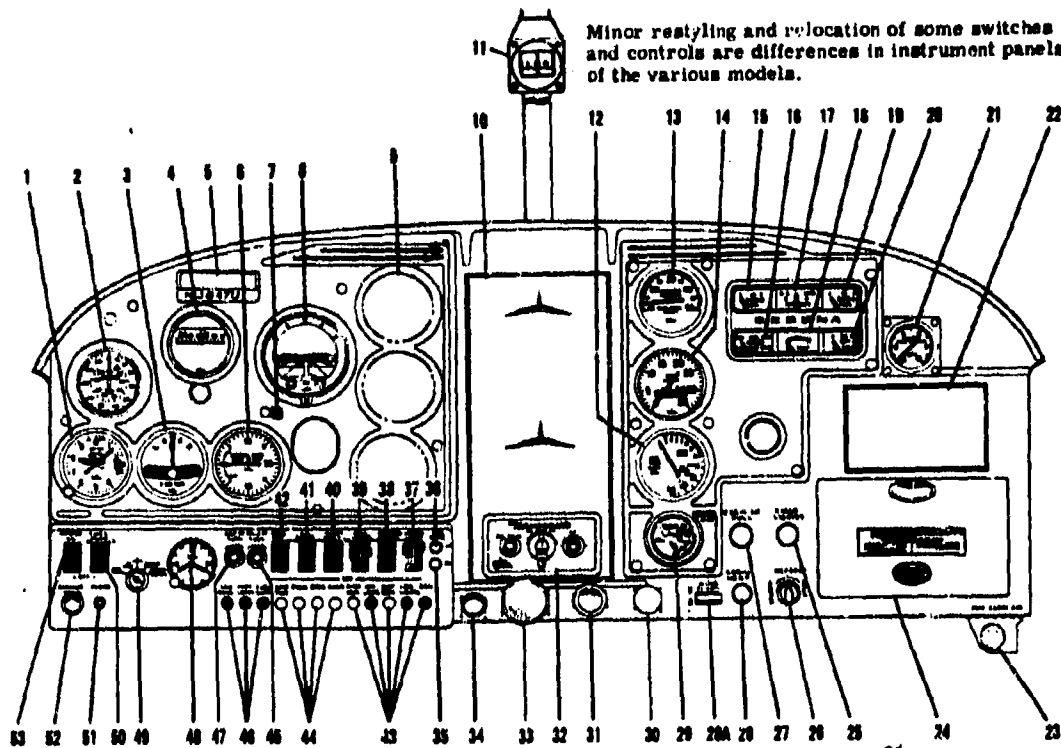


FIGURE 6. SAMPLES OF NONSTANDARDIZED INSTRUMENT PANEL



NOTE



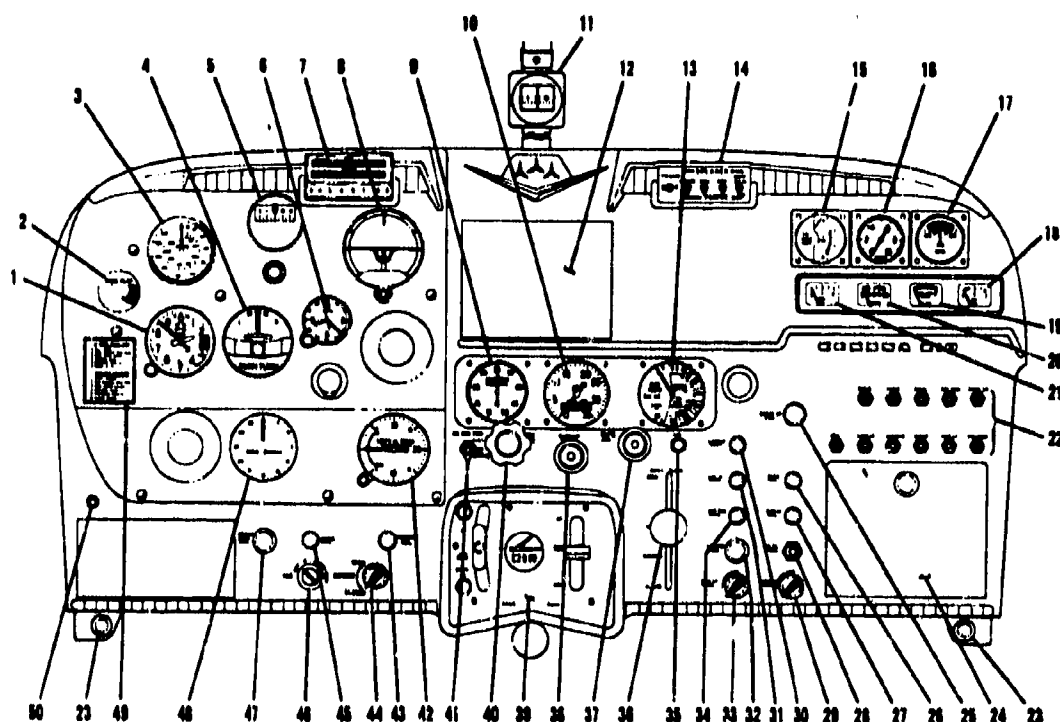
NOTE

If shockmount has unequal thread length, install shorter threads through stationary panel.

- |                                    |                                       |                                |
|------------------------------------|---------------------------------------|--------------------------------|
| 1. Altimeter                       | 20. Oil Pressure Gage                 | 37. Landing Lights Switch      |
| 2. Airspeed Indicator              | 21. Suction Gage                      | 38. Rotating Beacon Switch     |
| 3. Turn-and-Bank Indicator         | 22. Radio Space                       | 39. Navigation Light Switch    |
| 4. Directional Gyro                | 23. Cabin Air Knob                    | 40. Pitot Heater Switch        |
| 5. Compass Correction Card         | 24. Map Compartment                   | 41. Oil Dilution Switch        |
| 6. Vertical Speed Indicator        | 25. Cigar Lighter                     | 42. Radio Switch               |
| 7. Vacuum Lights Test Switch       | 26. Defrost Knob                      | 43. Circuit Breakers           |
| 8. Gyro Horizon                    | 27. Cabin Air Knob                    | 44. Circuit Breakers           |
| 9. Optional Instrument Space       | 28. Cabin Heat Knob                   | 45. Radio Light Rheostat       |
| 10. Radio Space                    | 28A. Flap Switch(except 210B & C)     | 46. Circuit Breakers           |
| 11. Magnetic Compass               | 29. Wing Flap Position Indicator      | 47. Instrument Light Rheostat  |
| 12. Fuel Flow Indicator            | 30. Mixture Control                   | 48. Clock                      |
| 13. Manifold Pressure Gage         | 31. Propeller Control                 | 49. Ignition - Start Switch    |
| 14. Tachometer                     | 32. Optional Nav-O-Matic Control Unit | 50. Auxiliary Fuel Pump Switch |
| 15. Fuel Quantity Indicator        | 33. Throttle                          | 51. Microphone Jack            |
| 16. Cylinder Head Temperature Gage | 34. Induction Hot Air Knob            | 52. Fuel Strainer Drain Knob   |
| 17. Ammeter                        | 35. Gear Down Indicator Light         | 53. Master Switch              |
| 18. Oil Temperature Gage           | 36. Gear Up Indicator Light           | 54. Shock Mount                |
| 19. Fuel Quantity Indicator        |                                       | 55. Ground Strap               |

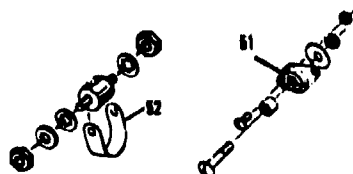
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FIGURE 7. SAMPLE OF NONSTANDARDIZED INSTRUMENT PANEL



#### NOTE

If shockmount has unequal thread length, install shorter threads through stationary panel.



#### NOTE

The 210 and 210A instrument panels are identical except for minor styling changes and switch relocations.

- |                                 |                               |                                |
|---------------------------------|-------------------------------|--------------------------------|
| 1. Altimeter                    | 19. Oil Temperature Gage      | 35. Generator Warning Light    |
| 2. Wing Flap Position Indicator | 20. Oil Pressure Gage         | 36. Cowl Flap Lever            |
| 3. Airspeed Indicator           | 21. Fuel Quantity Indicator   | 37. Mixture Control            |
| 4. Turn-and-Bank Indicator      | 22. Circuit Breakers          | 38. Propeller Control          |
| 5. Directional Gyro             | 23. Cabin Air Knob            | 39. Power Pack (See Section 5) |
| 6. Clock                        | 24. Map Compartment           | 40. Throttle                   |
| 7. Compass Correction Card      | 25. Cabin Heat Knob           | 41. Auxiliary Fuel Pump Switch |
| 8. Gyro Horizon                 | 26. Radio Switch              | 42. Vertical Speed Indicator   |
| 9. Manifold Pressure Gage       | 27. Pitot Heater Switch       | 43. Induction Hot Air Knob     |
| 10. Tachometer                  | 28. Oil Dilution Switch       | 44. Defrost Knob               |
| 11. Magnetic Compass            | 29. Radio Light Rheostat      | 45. Master Switch              |
| 12. Radio Space                 | 30. Landing Light Switch      | 46. Ignition - Start Switch    |
| 13. Fuel Flow Indicator         | 31. Navigation Light Switch   | 47. Fuel Strainer Drain Knob   |
| 14. Radio Selector Switches     | 32. Cigar Lighter             | 48. Radio Compass              |
| 15. Cylinder Head Temp. Gage    | 33. Instrument Light Rheostat | 49. Check List                 |
| 16. Suction Gage                |                               | 50. Microphone Jack            |
| 17. Ammeter                     |                               | 51. Shock Mount                |
| 18. Fuel Quantity Indicator     |                               | 52. Ground Strap               |

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FIGURE 8. SAMPLE OF NONSTANDARDIZED INSTRUMENT PANEL

demanding of the pilots, less time is available to him in which to act, and yet he requires more time than previously." Mr. Stieglitz, a design safety engineer, presented his paper in July 1952--25 years ago."

What was true then is even more applicable today, given the complexity of today's aircraft and air traffic control environment. The FAA publication, "Instrument Flying Handbook" (reference 38) makes the observation that in the not too distant past, visual (contact) and instrument flying were considered separate and distinct skills. Little, if any, consideration was given to correlating instrument indications (if available) with the visual aspects of aircraft attitude. At that time the nonprofessional civilian pilot had neither the equipment to fly safely on instruments nor the need or interest to do so. With the advent of faster aircraft, more reliable instruments and radio equipment, and more effective radio and ground services, the traditional distinction between visual and instrument flying has undergone corresponding changes.

A major achievement in eliminating the differences between visual and instrument flying was the institution and promotion of primary "integrated type flight instruction." As defined in the FAA publication AC-61-21, "Flight Training Handbook," integrated flight instruction means instruction in which students are taught to perform each flight maneuver by both outside visual reference and reference to instruments from the first time the maneuver is introduced. The integrated type of flight instruction, while not a substitute for instrument training, is an excellent foundation for later formal training for the instrument rating.

The concept of integrated flight training, however ideal, is obviously hindered if there is no systemized arrangement of the basic flight instruments. Given random arrangements of these instruments, there is an unnecessarily heavier pilot workload. Should the student receive instruction in a variety of training aircraft, he does not have the opportunity to develop a consistent systemized pattern of referring to the aircraft instruments in the course of his integrated flight instruction.

The SAE committee A-23C (Cockpit/Cabin Standardization-General Aviation Aircraft) recognized the need for a systematic arrangement of instruments in order: "to make transition easier, help eliminate pilot confusion and possible mismanagement of aircraft, and to establish a commonality between aircraft instrument panel arrangements." The committee developed and published ARP 1166, "Instrument Panel Arrangement for Fixed Wing Aircraft Under 12,500 Pounds" (figure A-7). This document, issued in May 1970, recommends a revised arrangement of six flight instruments structured around the T configuration that is standard for transport category aircraft. The ARP also recommends the location for two very high frequency omnidirectional radio range (VOR) displays.

Inspection of three major manufacturers' models of current production aircraft disclosed a unified adherence to the basic T instrument arrangement. The configuration was common to all aircraft examined with the exception of some aerobatic and cropdusting models. Also significant is that in addition to the

instruments comprising the T (airspeed, attitude, altitude, and direction), the location of the turn/slip indicator (turn coordinator) and the vertical speed indicator (VSI) has resulted in a "revised" Basic Six arrangement for late model FAR 23 aircraft. The configuration is shown in figure 9.

Table A-3 of appendix A indicates the number of adverse comments concerning the arrangement and location of the basic flight instruments. The consensus of the pilots interviewed was that the lack of standardization of the flight instrument arrangement increased pilot workload, especially for instrument flight rules (IFR) flight.

#### ACCIDENT DATA.

An accident data search identified no accidents which might be directly attributed to a lack of standard instrument arrangement. Nor do the NTSB accident statistics define a category of accidents attributable to "pilot workload." This doesn't mean that such accidents do not happen. There is sufficient reason to believe that accidents of this type, i.e., pilot workload, would be considered more as a "factor contributing to" rather than "a cause for" the accident. Furthermore, these accidents might well be masked under the established accident categories of: (1) improper IFR operations, (2) instruments--failed to read or misread, (3) lack of familiarity with the aircraft, and (4) pilot fatigue. For the year 1974, these four accident causes accounted for 283 accidents, of which 91 were fatal.

Similarly, the more serious accident causes such as "continued VFR flight into adverse weather" and "spatial disorientation" might camouflage the pilot workload/nonstandard instrument arrangement from recognition as contributing factors. These two accident causes, respectively, accounted for 843 and 620 fatal accidents during the 1970 through 1975 period. The spatial disorientation type of accident generally occurs when external visual references are obscured by clouds, fog, haze, dust, darkness, or other phenomena, unless visual reference is transferred to aircraft instruments. The NTSB accident data for the years 1970 through 1974 show that 80 percent or more of the pilots involved in spatial disorientation accidents were noninstrument-rated pilots. It is possible that had the pilots been instrument rated, and/or had they been exposed to integrated flight instruction with a standardized instrument arrangement, the number of spatial disorientation accidents might have been reduced.

Accident data for 1974 (reference 13) included 141 accidents associated with precision and nonprecision instrument approaches resulting in 142 fatalities. There are no recorded data available to determine what type of instrument arrangement existed on board the aircraft at the time of accident, or if the lack of a standardized instrument arrangement was a contributing factor. Notwithstanding these unknowns, extensive air carrier studies have proved that the basic T arrangement is most effective in reducing pilot workload during the instrument approach, the crucial phase of flight which makes the most demands on the pilot.

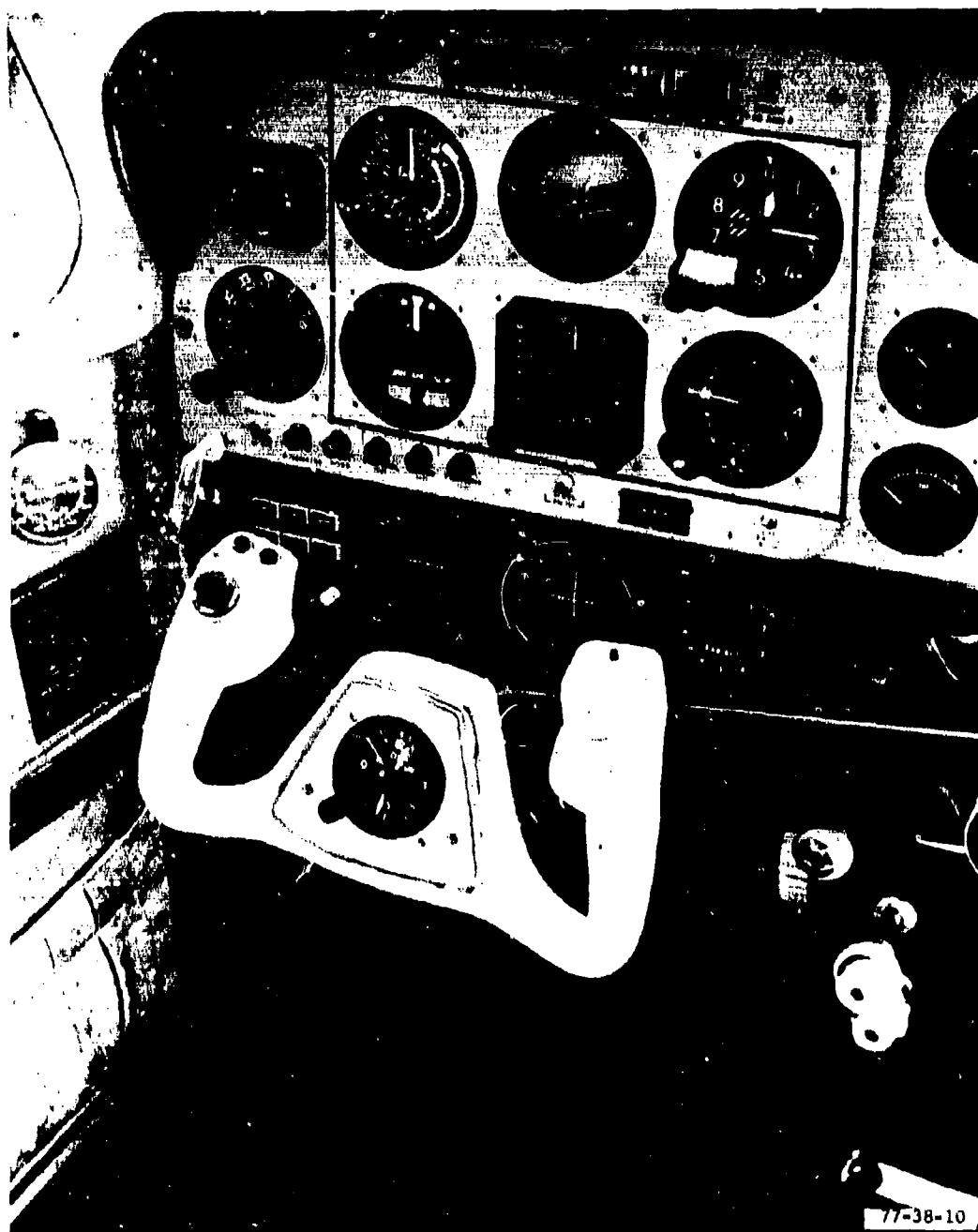


FIGURE 9. EXAMPLE OF A REVISED BASIC SIX INSTRUMENT CONFIGURATION

Student pilot exposure to a basic T configuration, coupled with integrated training from the indoctrination flight to pilot certification, can do much to instill pilot confidence in ability to fly the aircraft, establish consistent scanning patterns, reduce pilot workload, and lessen transitional difficulties associated with flying different aircraft.

#### STATUS OF REGULATIONS.

FAR 23.1321 states: "For each airplane of more than 6,000 pounds maximum weight, the flight instruments required by 23.1303 and as applicable by Part 91 of this chapter must be grouped on the instrument panel and centered as nearly as practicable about the vertical plane of the pilot's vision."

The flight and navigation instruments required by FAR 23.1303 are an airspeed indicator, an altimeter, and a magnetic direction indicator. FAR 91.33(b) repeats these minimum basic flight instruments required for VFR flight under FAR 91.33(b). No additional flight instruments are required for night flight under FAR 91.33(c). Thus, it appears that aircraft over 6,000 pounds not approved for IFR flight are not required to have a basic T instrument arrangement since under the regulations for VFR day and night, there is no requirement for an attitude indicator or a gyroscopic directional indicator.

However, if aircraft above the 6,000 pounds weight are to fly IFR, the basic T arrangement must be installed because the additional flight instruments of attitude gyro and directional gyro are needed in addition to the basic VFR flight instruments. The implication is that IFR capability not weight is the primary requirement for the basic T arrangement.

In view of this reasoning, the phrase, "of more than 6,000 pounds" does not necessarily affect general aviation FAR 23 aircraft of more than 6,000 pounds certificated for VFR flight only.

The requirement for a basic T arrangement for instrument flight would then depend on the aircraft being equipped with those instruments as applicable under FAR 91.33. Since current/late model production aircraft under 6000 pounds indicate a predisposition on the manufacturer's part to continue installation of the basic T, its requirement by regulation would improve the safety of operations for flight training (i.e., integrated flight instruction), night, and IFR flight operations through greater instrument panel standardization.

#### RECOMMENDATION.

Consideration should be given to regulatory action to require that FAR 23 aircraft of any weight used in either flight training, night, or IFR operations have the basic flight instruments arranged in accordance with the T configuration specified in FAR 23.1321 if sufficient panel space is available.

## POWERPLANT INSTRUMENTS

### THE PROBLEM.

Arrangement and location of powerplant instruments on the instrument panel is not always analogous to the sequenced arrangement of the corresponding powerplant controls. This lack of good human engineering imposes an unnecessary workload on the pilot.

### RELEVANT FACTORS.

More than 55 percent of the pilots and flight instructors interviewed commented that the location and arrangement of the powerplant instruments, specifically manifold pressure, tachometer and fuel flow, are not sequenced as are the throttle propeller, and mixture controls. In a number of different model aircraft, either the powerplant instruments were not grouped closely on the panel, or their positions were reversed relative to the positions of the powerplant controls. Pilots reported that the lack of close grouping of these instruments required a larger instrument scan and placed an increased and unnecessary workload on the pilot. Flight instructors reported that on numerous occasions their students, while reducing power with throttle, would be monitoring the tachometer located directly above the throttle, instead of monitoring the manifold pressure gauge, which in this case was positioned above the propeller control. FAR 23.1321(b) specifies: "For each multiengine airplane, identical powerplant instruments must be located so as to prevent confusion as to which engine each instrument relates." But there is no regulatory requirement for powerplant instrument grouping or positioning on the instrument panel to make location compatible with powerplant control arrangement for single or multi-engine airplanes.

Other than the comments and opinions received from those interviewed, there are no objective data in the form of accident or incident statistics to justify a regulatory need for powerplant instrument arrangement to correspond with powerplant control arrangement. However, the compatibility of powerplant display location with the relevant powerplant controls is well-recognized from the viewpoint of good human engineering design. The Cornell-Guggenheim Aviation Safety Center recommends that each control be as close as possible to the indicator it affects, and has listed inappropriate layout of controls and displays as a factor contributing to operator fatigue (reference 39). United States Air Force military standard 803A-2 (reference 40) requires that: "...controls should normally be located adjacent to their associated displays ...and controls which are operated together should be grouped together, along with their associated displays."

### DISCUSSION.

An inspection of current production aircraft disclosed a general trend to adhere to the desired arrangement of the powerplant instruments. However, under certain conditions, especially in multiengine aircraft, the crowded instrument

panel does not allow for a desirable grouping or sequenced arrangement. A typical single-engine example is shown in figure 10. The manufacturer at times must position the powerplant instruments in a vertical line on the panel while the standard arrangement of the powerplant controls is a horizontal arrangement, either on the panel or on the powerplant control quadrant. Ideally, the manifold pressure gauge should be located on the panel in line with and above the throttle, the tachometer in line with and above the propeller control, and the fuel flow indicator in line with and above the mixture control. This arrangement is not always possible when, for example, the indications for manifold pressure and fuel flow are incorporated in one instrument (figure 10).

Because of such restrictions, it would be impractical to attempt to regulate exactly the location and arrangement of the powerplant instruments. More practical would be the implementation of an AC, ARP, or other guidance to keep the powerplant instruments close to each other and, where feasible, retain an order or arrangement, either in the horizontal or vertical plane, that conforms to the sequence of the irrespective controls. This design philosophy would be in harmony with GAMA's proposed powerplant control arrangement and would reduce pilot workload.

#### RECOMMENDATION.

An AC or other appropriate design guidance should be formulated to stress the advantages of having powerplant instruments arranged to be consistent with the sequenced arrangement of the powerplant controls. The establishment of the natural relationship of powerplant instruments to powerplant controls can eliminate pilot confusion and reduce pilot workload.

### INSTRUMENT LIGHTING

#### THE PROBLEM.

The flight instructors surveyed frequently complained about inadequate instrument lighting in certain small aircraft. Many pilots indicated that they carry a flashlight, not just as an emergency backup light, but as a necessary aid for use in reading instruments, checking items such as circuit breakers and flap position indicators, and in tuning radio frequencies. A specific complaint was voiced against a single floodlight located on the ceiling behind the pilot as a sole source of instrument panel light. In night instrument flight, the instructors found that such a light illuminates a chart held in front of the pilot, but the chart, in turn, blocks the light to the panel. The instructors in the survey pointed out that some training airplanes with only rudimentary instrument lighting are used for night flying instruction.

At the June 1976 Aircraft Operations and Maintenance Show in Reading, Pennsylvania, current production aircraft were inspected. The vast majority had adequate instrument panel lighting but the practice of installing a single flood light for panel illumination still existed.



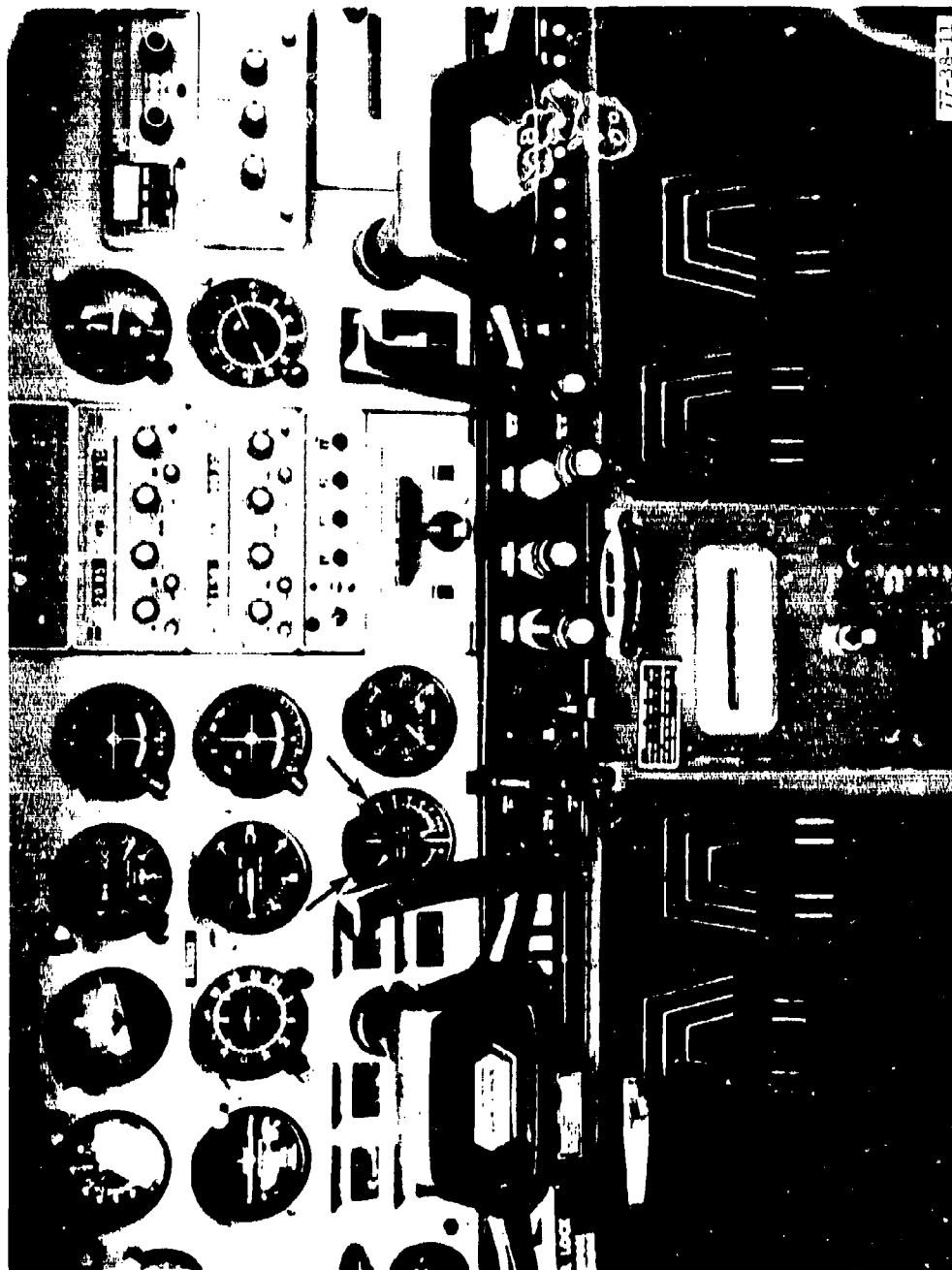


FIGURE 10. COMBINATION OF POWER PLAN INSTRUMENTS

### RELEVANT FACTORS.

FAR 23.773(b) requires that, if certification for night operation is requested, it must be shown in night flight tests that the pilot's compartment is free from glare and reflections. However, this requirement is interpreted as insuring against improper external, rather than internal, lighting.

FAR 23.1321 presents the general rule that each instrument must be plainly visible to the pilot.

FAR 23.1381 requires that instrument lights must make each instrument and control easily readable, be installed to avoid direct or reflected glare in the pilot's eyes, and be safe from electrical shorting. Further, the statement is appended that: "A cabin dome light is not an instrument light."

The three sections of FAR 23 summarized imply that: (a) instrument lighting is required, and (b) installed instrument lighting must be effective. However, this interpretation is questionable. When instrument lighting is installed, it must meet the requirements of FAR 23, but it may be omitted entirely and the airplane still can be certificated.

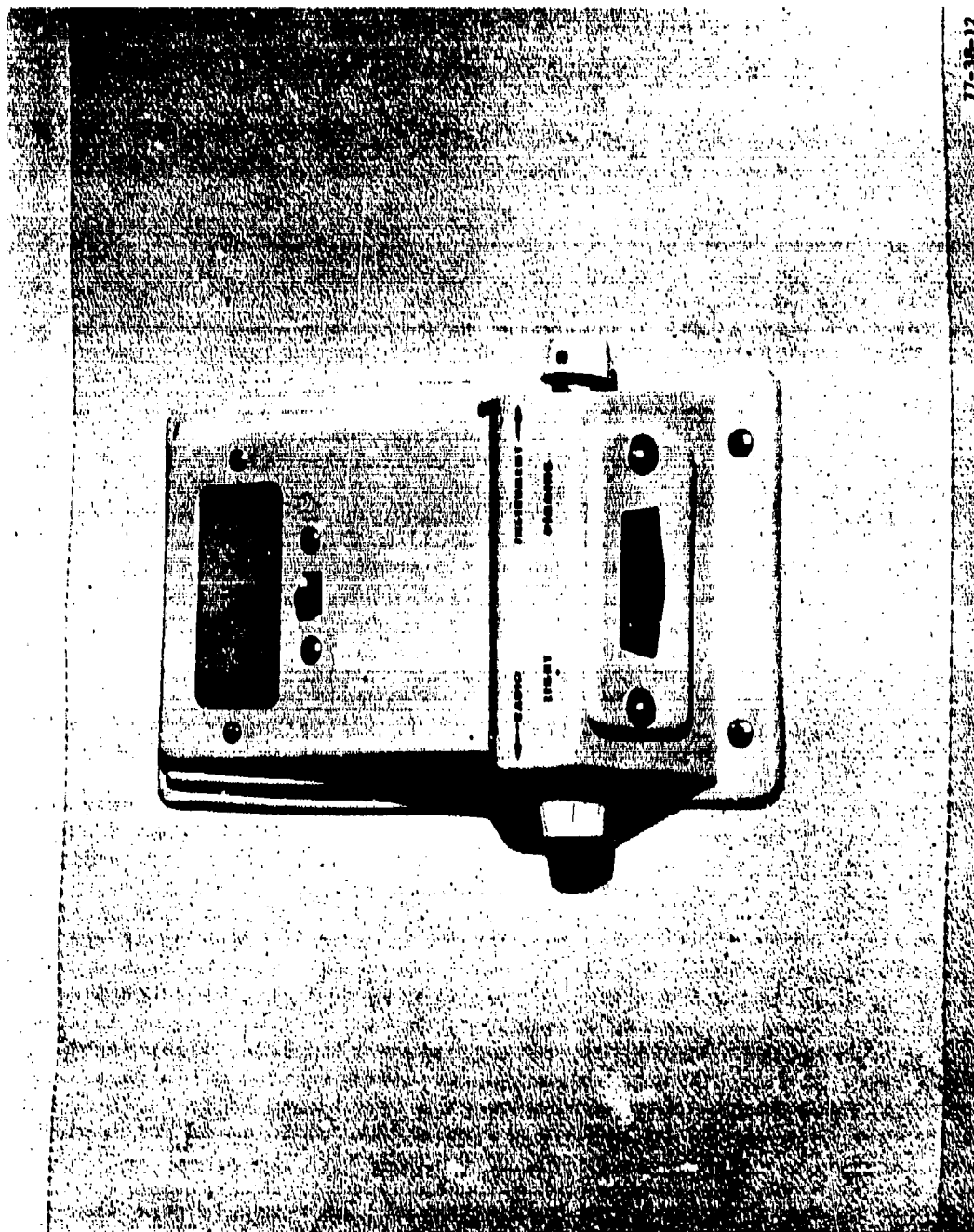
FAR 121.323, referring to operation of air carrier and other large aircraft, includes the requirement that effective instrument lights must be provided if an airplane is to be operated at night. From an operational viewpoint, this rule has no counterpart for small aircraft, since there is no requirement for instrument lighting specified under FAR 91.33(c) for night VFR equipment.

### ACCIDENT DATA.

No accidents were found that were attributed directly to the lack of instrument lights or to inadequate lighting of the cabin or panel. This does not indicate that there is no safety problem; it may, however, mean that pilots are cautious enough to supplement installed lighting with flashlight or penlight sources, as recommended in "The Pilot's Night Flying Handbook" (reference 41). The book notes: "There is little standardization in the cabin and instrument lighting of small aircraft. Factory-installed lights are often minimal and leave critical areas poorly illuminated... In some aircraft, illumination is blocked by the instrument panel, or light beams fail to strike control knobs or levers mounted near kick pads or below the panel." Reference 41 also indicated that engine gauges were inadequately lighted in a particular model, and the fuel selector was not lighted at all. It concludes: "In most general-aviation planes...a flashlight is necessary for normal night operation."

### DISCUSSION.

There are four classes of systems used to light instruments and controls. The simplest is floodlighting, provided in the minimum system by a single red or white light on the cabin ceiling (figure 11). The second consists of eyebrow and post lights adjacent to the instruments. Integral lights, the third class, may spread light over instruments from locations just under the panel surface. The fourth type, transilluminated systems, may provide integral back lighting.



77-38-12

FIGURE 11. AIRCRAFT CABIN DOME LIGHT

Red lighting, at one time considered essential for military operations, is now outdated in most civil applications. The original purpose was to maintain dark adaptation, but in civil use this is less important than the ability to read color-coded instrument displays, tables, charts, and manuals.

Post lights are preferred for easy lamp replacement, but are vulnerable to the wear-and-tear of daily operation. Also, the sharp projections increase the lethality of the panel.

Common home appliances have integral lighting as do automobiles. It is surprising that airplanes do not have equally adequate lighting. However, integral lighting installation and repair are costly, and the facts are not available to prove that flood lighting and post lighting are inherently unsafe. Hence, all types probably will continue to be allowed.

#### RECOMMENDATIONS.

The requirement in FAR 121 (Certification and Operations: Domestic, Flag, and Supplemental Air Carriers and Commercial Operators of Large Aircraft) that pilots of large aircraft must have instrument lighting for night operation should be paralleled in the regulations for small aircraft. Effective cockpit lighting which illuminates the instruments, all essential controls, and avionics, should be required for all night operations and for training which may occur in low visibilities, twilight, and at night. A flashlight should also be required equipment in light part 91 aircraft, both for use in preflight examination of the aircraft and for emergency use in night flight.

While it may be reasonable to permit the use of floodlighting as a means of meeting these panel and control lighting requirements, it is unreasonable to allow a single light for this purpose. Not only is there a risk of lamp failure when using one light, but the problem of light blocked by the pilot's body, a handheld chart, or other material is critical. Workload is increased when the pilot must put down the chart to see the panel or has difficulty reading the instruments on the panel. Hence, a minimum acceptable floodlight system would be two lights, pointing from different angles so that one would continue to light areas in which light was blocked from the other. A system of this sort is illustrated in figure 12, but it should be noted that the lights are too close to each other. Relocation of one light to the side might provide better light distribution, but would require judgment of each case on its own merits. The best action to take for improved and standardized night lighting would be to amend present FAR 23.1381 which now states that a cabin dome light is not an instrument light. This exclusion of a cabin dome light as an instrument light could be expanded to exclude a single floodlight as an acceptable instrument light.

The evaluation by FAA engineering in certification should insure that instrument lighting meets at least the following standards:

1. Lamps should be replaceable without major disassembly, and spare lamps should be readily accessible.

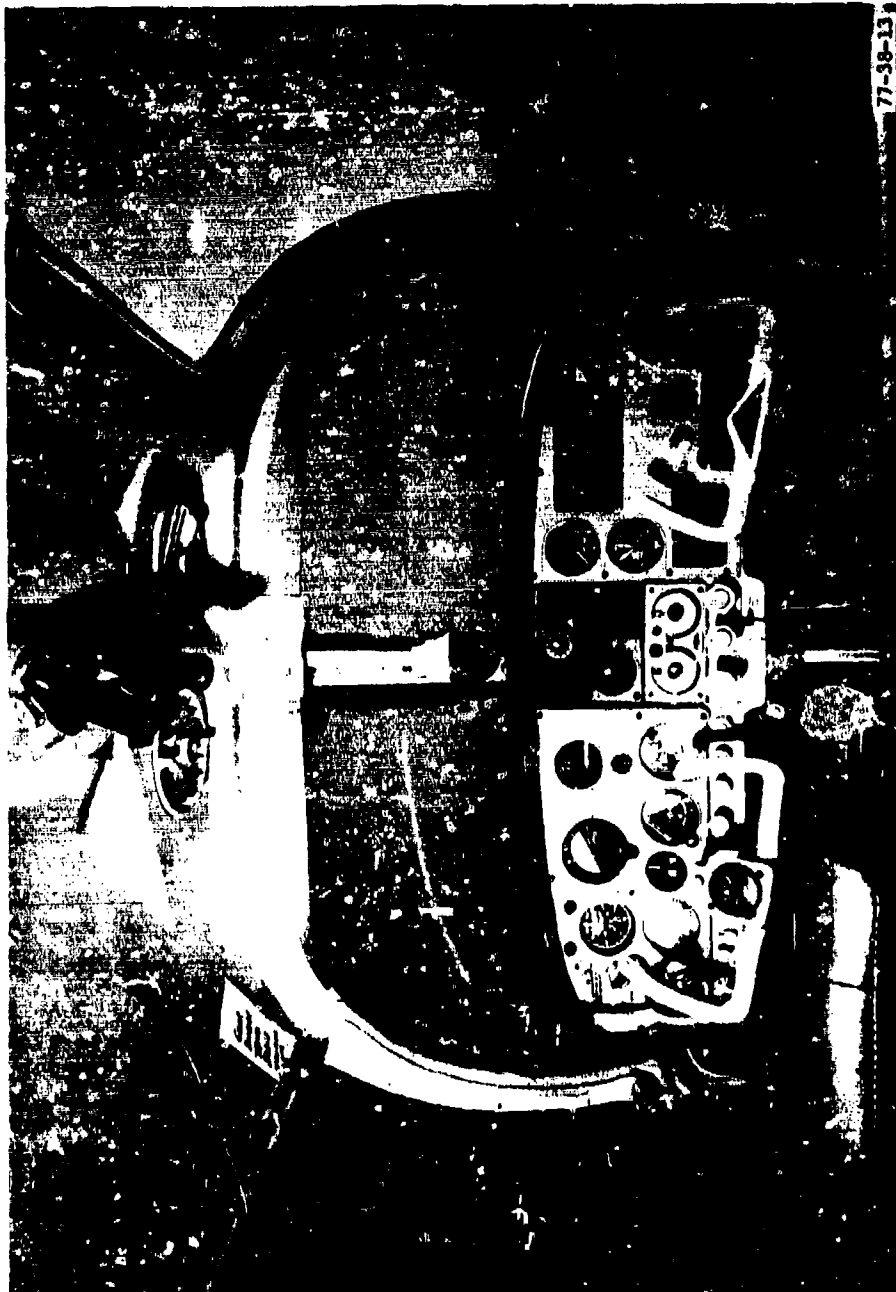


FIGURE 12. OVERHEAD CABIN FLOODLIGHTING SYSTEM

2. Instrument lighting should be white, with provision for added color filters being allowed.
3. With pilot seats occupied, there should be reasonably-even light distribution over all essential instruments and control markings.
4. Light intensity should be adjustable over a sufficient range to support operation in the normal range of twilight and night conditions.

## ELECTRICAL CIRCUIT PROTECTIVE DEVICES

### THE PROBLEM.

An inspection of general aviation aircraft disclosed a wide diversity in the location and arrangement of circuit protective devices. In some aircraft, these devices were located in areas not readily visible to the pilot. Furthermore, there was no distinctive arrangement or logical separation of critical from noncritical protective devices.

### RELEVANT FACTORS.

The selection, application, and inspection of electric over-current protective devices are detailed in the SAE ARP 1199. This document provides technical and application information used by the designers of aircraft electric systems and support equipment for the selection of over-current protective devices. This document provides detailed and technical information on the three types of circuit protective devices: circuit breakers, fuses, and limiters. FAR 23.1357 "Circuit Protective Devices" specifies the minimum requirements of circuit breakers relevant to certification of FAR 23 aircraft.

Over 60 percent of the pilots and flight instructors interviewed commented on circuit protective devices (table A-3 of appendix A). Criticized were the lack of standardized type, location, and arrangement of circuit protective devices within and between the aircraft models flown by these pilots.

Their comments and opinions did not emphasize the need for standardization of these factors for improved flight safety so much as the need for standardization to eliminate an irritating workload of locating, identifying, and resetting tripped circuit breakers or replacing blown fuses. Pilots were vehemently opposed to the use of fuses in electrical systems that could just as easily and safely use circuit breakers. Compared with the ease of resetting a tripped circuit breaker, replacing a blown fuse is cumbersome. Getting new fuses from the map case, identifying the appropriate amperage, unscrewing the fuse cap, removing the blown fuse, inserting the new fuse, and perhaps dropping either the fuse cap or the fuse are all minor but irritating tasks, especially under a heavy workload, night operations, or during a critical phase of flight. The frequently heard statement "Fuses in aircraft should be abolished," describes succinctly pilots' opinions of these devices.

Inspection of a variety of older aircraft models (1965-1968) revealed circuit breakers located in areas not directly visible to the pilot. One model had circuit breakers located on the under edge of the instrument panel. Detection of a tripped circuit breaker could be accomplished only by feel. Pilots also reported that tripped circuit breakers were sometimes difficult to detect because the tripped circuit breaker did not protrude sufficiently, or its tripped state was less noticeable because the uniform color of the breaker was similar to the color of the panel encasing the circuit breakers.

#### ACCIDENT DATA.

The NTSB accident data for general aviation aircraft during the period 1970 through 1974 revealed that malfunctioning circuit protective devices and tripped circuit breakers were cited as a cause in 28 accidents and as a contributing factor in 56 accidents. It is highly probable that some minimal circuit breaker design changes as observed in current model aircraft and described later would reduce the frequency of these occurrences.

#### DISCUSSION.

Inspection of circuit protective devices in late model aircraft revealed some designs that minimize the problems associated with these devices.

The general trend was the use of circuit breakers, rather than fuses, where feasible. Dual color coding of the circuit breaker (head different from stem) provides color contrast for easy detection of the tripped state of the breaker (figure 13). In single-engine aircraft, the general location of the circuit breaker panel is the right side of the instrument panel (figure 14). In multi-engine aircraft, circuit breaker panels were located by the pilot's left side, either on a console, or on the left panel of the fuselage interior. Either location is visible and easily accessible to the pilot (figure 15). Some manufacturers have color-coded those circuit breakers which are critical to flight, but no standard color scheme has been adopted.

These designs were definite improvements over older fuse/circuit breaker systems, and should reduce pilot workload.

#### RECOMMENDATIONS.

Regulatory action to standardize the location of electrical protective devices would be extremely difficult and overly restrictive because cockpit space is limited by the design, auxiliary equipment, and complexity of the aircraft.

However, desirable and practical human engineering features of circuit protective devices can be achieved through a recommended design practice or amendment of the existing ARP 1199 to include the following recommendations:

1. Eliminate the use of fuses, where possible, in those electrical systems where a reset circuit breaker will not compromise the safety of the aircraft or its essential electrical subsystems.



FIGURE 13. EXAMPLE OF VISIBLE CIRCUIT BREAKERS IN A MULTIENGINE AIRCRAFT



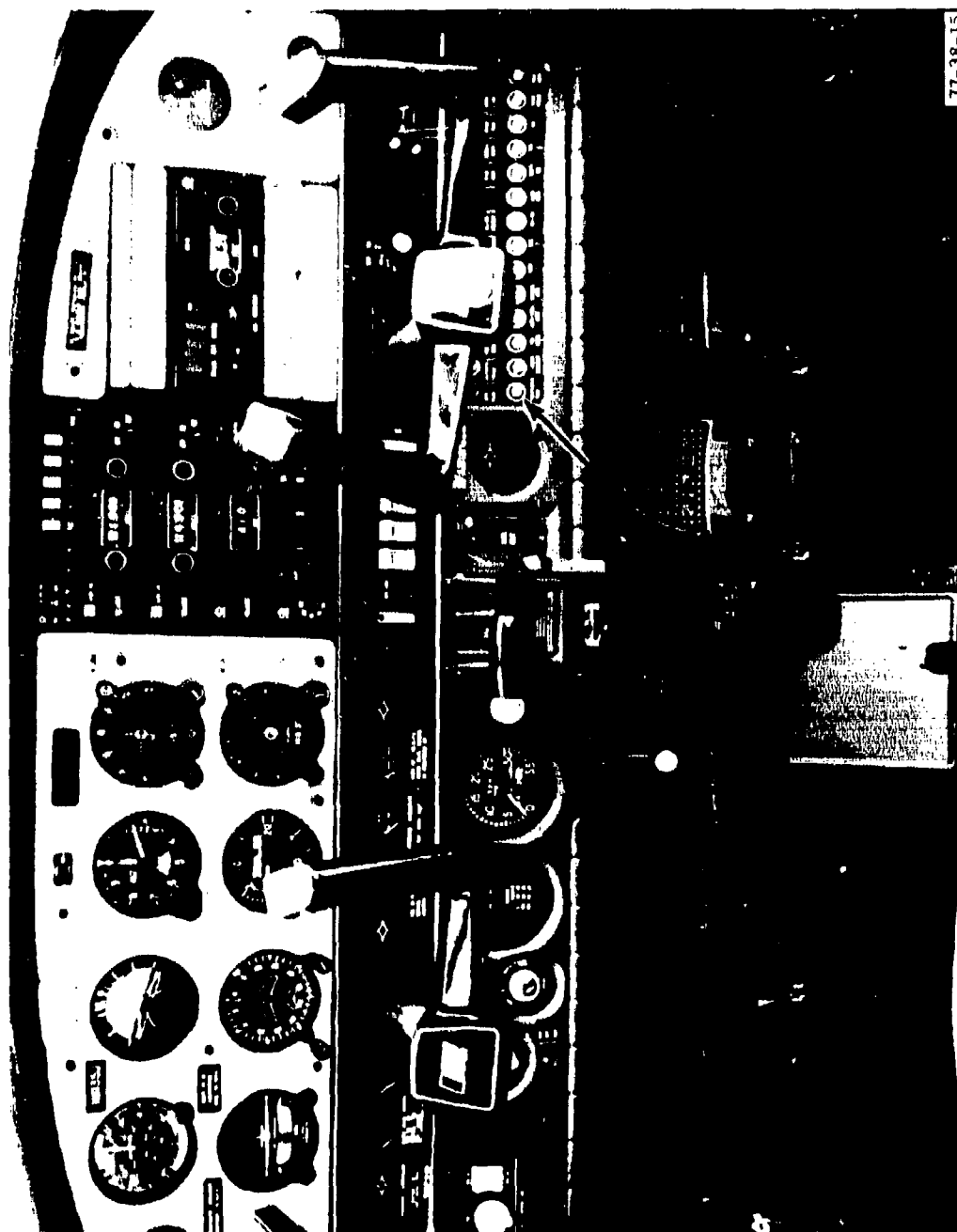


FIGURE 14. TYPICAL CIRCUIT BREAKER LOCATION IN A SINGLE ENGINE AIRCRAFT



FIGURE 15. CIRCUIT BREAKER PANEL—MULTIENGINE AIRCRAFT

2. Circuit breakers should be easily identifiable and readily accessible to the pilot. Circuit breakers protecting critical circuits should be distinct and separated from those circuits protecting less critical systems. Standardized color coding is recommended.

3. The tripped state of a circuit breaker should be readily apparent by color coding of the inner portion. Further, the circuit breaker heads should contrast with the color of their panel or surrounding area.

### SUMMARY OF RESULTS

The goal of this effort was to identify those characteristics of general aviation cockpit design whose improvement through increased standardization and/or better human engineering, would both contribute to safety and efficiency of flight and also be feasible and practical.

Information was collected from three sources: a survey of experienced and instructor pilots, accident analysis, and a literature review.

Pilots reported difficulties caused by lack of standardization, outlined design features important to flight safety, and offered examples of accidents and incidents due to workload or confusion-inducing cockpit characteristics. Accident reports were studied and statistics were tabulated to determine frequency of accidents attributed to cockpit design features. Finally, airworthiness standards, other government guidelines on cockpit design, industry studies and reports, and design guidance documents were examined to take advantage of prior work on the topic of cockpit standardization.

It was apparent early that the general aviation industry is wary of government efforts to dictate cockpit standardization through regulation by law. Because of the wide diversity of aircraft types and sizes, the design differences in cockpits of aircraft which were certificated at different times and produced substantially unchanged in subsequent years, and the possibility of stifling design innovation in new aircraft, the aircraft manufacturers prefer voluntary standardization rather than regulation. This standardization is through industry-wide agreements on design guidelines. The industry questions whether greater cockpit standardization is essential to improve flight safety, in that pilots have been flying aircraft with significant cockpit differences for a long time with evident success. Hence, this effort deliberately avoided utopian thinking such as a proposal for a universal, ideal cockpit. Rather, the effort was made to anchor findings and conclusions in practical and documented advantages for improvement in safety.

The cockpit has two major functions: housing and protecting the pilot, and providing the man-machine interface of displays, controls, and aids that permit control of the aircraft. Priority protective function candidates for increased standardization were: seatlatching, upper torso restraints, exit door latching, and related features. Cockpit features important to flight control and management were: fuel systems, powerplant controls, flight instruments, powerplant instruments, instrument lighting, and electric circuit protection devices.

There are additional important cockpit features and functions which lack standardization and could benefit from greater uniformity. These include the pilot's external visibility, cockpit dimensions, avionics systems, control friction locks, safety placards, among others. However, areas such as these were not included because there was not a strong argument that safety would be improved significantly. In other cases where an important safety problem was noted greater standardization was impractical at this time within reasonable economic and production constraints. Thus, this treatment of cockpit standardization is an initial analysis only of those areas of cockpit design where standardization appeared important, timely, and economically reasonable.

#### STANDARDIZATION ACTIONS RECOMMENDED

To better house and protect the crew and other occupants of aircraft, the following areas of cockpit design are proposed for industry-wide standardization through changes in Federal Airworthiness Standards, FAR 23, or other standards or guides as appropriate.

1. All aircraft should have a convenient and safe body restraint system for reduction of injuries. Virtually all general aviation production aircraft are equipped with a standard or optional upper torso restraint in addition to the lap belt. Many of these restraints however, are the across-the-shoulder, or Sam Browne type and lack convenience features essential to customer acceptance and use. Objection to one NPRM requirement that the shoulder harness be used at all times was vigorous. Since the vast majority of survivable accidents occur during takeoff and landing, a minor part of the total flight time, this objection can be overcome by requiring restraint system use only during takeoff and landing. (Note: See recommendations under section SEATS AND BERTHS.)

Some systems are one piece, combined lap and shoulder belts with inertia reels to permit free movement and have self-retracting and storing features. These are found in current automobiles as well as airplanes and are frequently used. Cockpit standardization should require a restraint system with these minimum features, while recognizing that the dual-loop system, vertically circling both shoulders and sometimes called the "aircrew design," is superior, although more complex and expensive.

2. Adjustable pilot seats must be designed to provide reasonable assurance against inadvertent slippage which could result in pilot loss of control. Various aircraft now in production have adjustment track stops or dual latching mechanisms that preclude seat movement during aircraft acceleration which could impair the pilot's ability to control the aircraft. These features and other available design techniques make practical a requirement that pilot seats are designed to prevent inadvertent slippage.

3. Door latching mechanisms and latching status indications should be more standard and more positive in action. There is a lack of standardization in door latches, and certain common types are actually unsafe. As a result, the cautious, experienced pilot often tests the door latch and lock by pushing

his shoulder against the door. Otherwise, he may experience a sudden unexpected door opening in flight. This current production situation is unacceptable from the safety standpoint since available latching techniques can solve the problem. Another problem, requiring regulatory attention, is that some common aircraft doors cannot be opened from the outside when locked normally from the inside. While this feature may be acceptable in other forms of transportation such as the automobile, it can be a hazard to the airplane occupant since it may be necessary for a rescuer to open the cockpit door from the outside to aid or remove an injured person after an accident.

To increase the safety of flight, the following man-machine interface areas of cockpit design are proposed for standardization:

4. Fuel management systems should be standardized as proposed by previous studies and recommendations (GAMA) with the additional requirement that the tank selector be accessible to both pilots in side-by-side, dual-control aircraft. The fuel management system has been amply documented as a contributor to accidents through a wide diversity of design and operational features, some of which are poor from a human engineering point of view and constitute a virtual trap for the unwary pilot. Industry has proposed better standardization, and this proposal should be implemented. The added requirement that the selector be located so that both pilots can use it is practical in view of the possibility that the aircraft may be operated from either seat, and in the opinion of many pilots, the selector comes within the definition of an essential control.
5. Powerplant controls should conform to the standard arrangement, actuation, and coding proposed by the industry. The concepts of left-to-right sequence of throttle, propeller, and mixture controls, use of forward actuation for increased forward thrust, increased RPM, or more fuel, and knob shape and color coding have been accepted for revisions to FAR 23. Another important feature of the draft proposal is the location, actuation, and coding of the carburetor air heat or alternate air control, but it is recommended that the complete list of GAMA proposals be incorporated in FAR 23.
6. Basic flight instruments should be arranged in the widely accepted T pattern in all standard category general aviation aircraft in which sufficient space is available. The relationship of the attitude, direction, altitude, and airspeed indicators has been accepted by regulation in transport category aircraft and is almost universal in newer small aircraft equipped for instrument flight.
7. Powerplant instruments should conform to a standard arrangement. For maximum ease of use, the instrument sequence should correspond to the sequence of the related powerplant controls. A horizontal layout is preferable if space permits. Combined instrument presentations are acceptable if coded to avoid confusion.
8. Instrument lighting should be required for all aircraft approved for training or night flight. The present FAR 23 exclusion of a cabin dome light

as an instrument light should be expanded to exclude a single floodlight mounted behind the pilot.

9. Electrical protection should be provided by circuit breakers wherever feasible and should have a readily visible tripped state. They should be grouped and located to be easily accessible to the pilot. While the trend has been in this direction in recent cockpits, the present regulations should be revised to require circuit breakers where fuses are not preferable for safety, and the description of an acceptable breaker should specify an easily visible tripped state.

The preceding nine recommendations are the product of this project, but the task of supporting safety and efficiency through increased cockpit standardization requires continuing study and testing. The pilot inquiry and accident record search procedures used in the effort to justify increased standardization are not the only ways to gain insight into chronic problems in this field. Some questions can be answered only by real world tests, evaluations, and observations.

The data collected verify the need for regulatory standardization in many areas of cockpit design. FAR 23 regulation relating to cockpit design characteristics should be under continuing study and review. General aviation aircraft are not necessarily becoming larger or more complex in basic structure. But in the cockpit, it is undeniable that instruments, controls, avionics, and warning signals are getting more complex and have proliferated, making the panel overhead, and side areas more crowded and more demanding of pilot attention. Earlier cockpits had fewer elements, and a standard design and arrangement were not requisite. Standardization is required today, and will be even more critical in the future.

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APPENDIX A  
SUPPLEMENTARY DATA

TABLE A-1. COCKPIT SYSTEM DESIGN AREAS

1. COCKPIT GENERAL
  - a. Dimensional Criteria
  - b. Seat Belts and Restraints
  - c. Windscreen Visibility
  - d. Ventilation and Environment
  - e. Doors-Access
  - f. Noise
  - g. Placards, Markings and Manual
  - h. Heater/Defrost Control
2. FLIGHT CONTROL SYSTEM
  - a. Yoke
  - b. Elevator
  - c. Aileron
  - d. Rudder
  - e. Elevator Trim
  - f. Rudder Trim
  - g. Aileron Trim
  - h. Flaps/Indicator
  - i. Autopilot
  - j. Emergency
3. POWERPLANT CONTROL SYSTEM
  - a. Throttle
  - b. Mixture
  - c. Prop
  - d. Carburetor Heat
  - e. Turbo Control
  - f. Primer
  - g. Booster Pump
  - h. Cowl Flaps
  - i. Emergency
  - j. Warning System
  - k. Master Switch
  - l. Mag Switch
  - m. Starter Switch
4. FUEL MANAGEMENT SYSTEM
  - a. Fuel Selectors
  - b. Indicator (Quantity)
  - c. Fuel Flow Indicator
  - d. Booster Pump
  - e. Mixture Control
  - f. Carburetor Heat
  - g. Emergency
  - h. Warning System
5. FLIGHT INSTRUMENTS
  - a. Airspeed
  - b. Altimeter
  - c. Attitude Gyro
  - d. Directional Gyro
  - e. Magnetic Compass
  - f. Vertical Speed
  - g. Turn/Slip
  - h. Vacuum
  - i. Emergency
  - j. Warning
6. ENGINE INSTRUMENTS
  - a. Tachometer
  - b. Manifold Pressure
  - c. EGT
  - d. Cylinder Head Temperature
  - e. Oil Pressure
  - f. Oil Temperature
  - g. Fuel Pressure
  - h. Fuel Flow
  - i. Emergency
  - j. Warning
7. NAVIGATION AND COMMUNICATIONS SYSTEM
  - a. VOR Display
  - b. ILS/LOC/Glide Slope Display
  - c. ADF Display
  - d. VHF Tuning Head(s)
  - e. ADF Tuning Head
  - f. Transponder
  - g. RMI
  - h. Area Nav
  - i. DME
  - j. Marker Beacons
  - k. Audio Panel
  - l. Mike/Mike Jack
  - m. Speaker-Headphone Jack
  - n. Auto Coupler
  - o. Compass
  - p. Emergency
  - q. Warning
  - r. Clock
8. LANDING GEAR
  - a. Selector
  - b. Indicator
  - c. Warning
  - d. Emergency
9. ELECTRICAL SYSTEMS
  - a. Switches
  - b. Rheostats
  - c. Indicators
  - d. Circuit Breakers/Fuses
  - e. Selector
  - f. Warning
  - g. Emergency
10. LIGHTING SYSTEMS
  - a. Cabin Lighting
  - b. Instrument Lighting
  - c. Map Lighting
  - d. Exterior Lighting
  - e. Selector/Switches
  - f. Emergency
  - g. Warning
11. EMERGENCY SYSTEMS
  - a. Stall Warning/Signal
12. MISCELLANY
  - a. Parking Brake
  - b. Friction Locks
  - c. Detents
  - d. Control Locks
  - e. OAT Gauge
- I. ANTHROPOMETRIC FACTORS
  - Location
  - Accessibility
  - Size
- II. VISUAL FACTORS
  - Visibility
  - Readability
  - Color Coding
- III. POPULATION STEREOTYPE FACTORS
  - Logic of Operation
  - Confusion Factor
- IV. OPERATION FEEDBACK
  - Ease of Operation
  - Shape and Feel

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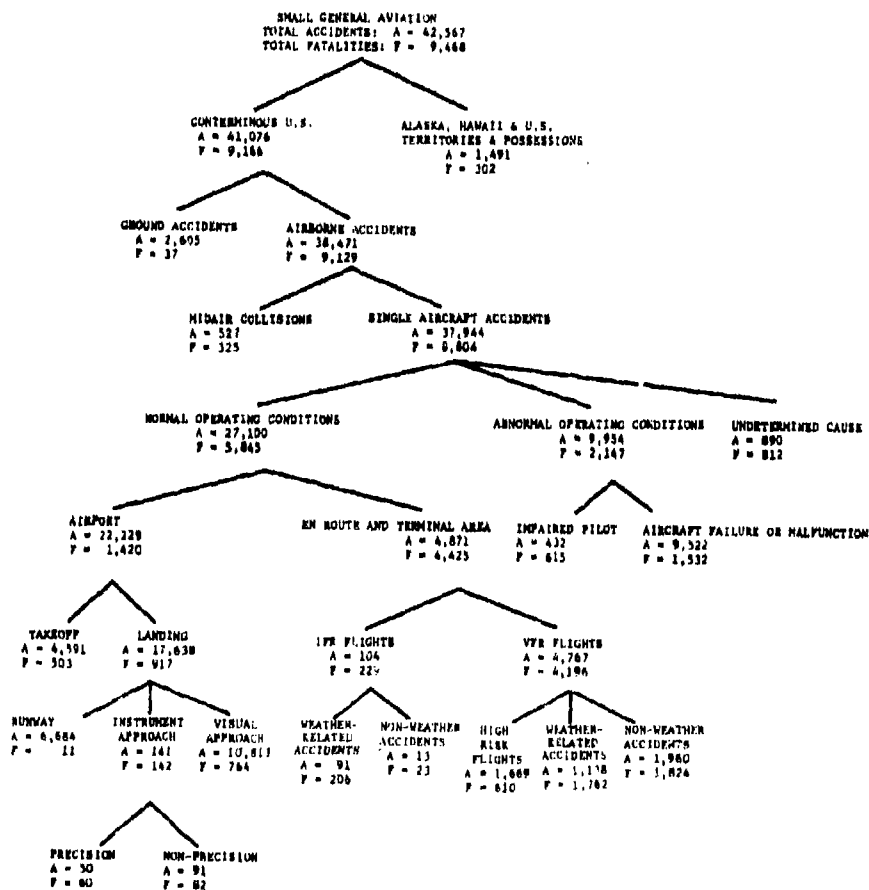
TABLE A-2. TABLE 7. PILOT COMMENTS ON COCKPIT SYSTEMS-DESIGN AREAS

Number of Pilot Comments	Item	Number of Pilot Comments	Item	Number of Pilot Comments	Item	Number of Pilot Comments	Item
39	Fuel Selectors	40	Cabin Dimensions	21	Turn/Slip Indicator	9	Starter Switch
37	Doors-Latches-Locks	38	Carburetor Heat Control	20	Aileron Trim	9	Vertical Speed Indicator
36	Flap Control/Indicator	37	Emergency Landing Gear	20	Turbo Control	9	Flight Instrument Warning
33	Mixture Control	37	Landing Gear Indicators	19	Cowl Flaps	8	Flight Control Emergency Systems
33	VOR Display	35	Landing Gear Selector	18	Fuel Fuel Indicator	8	Compass Emergency
32	Throttle	35	Parking Brake	18	Boost Pump (Fuel Management)	8	Emergency Light Systems
32	Tachometer	34	Attitude Gyro	18	Friction Locks	7	Rudder Controls
31	Fuel Indicators	34	Automatic Direction Finder (ADF) Display	17	Magnetic Compass	7	Powerplant Warning Systems
30	Circuit Breakers/Fuses	34	ADF Tuning Head	16	Carburetor Heat (Fuel Management)	7	Fuel Management Emergency Systems
30	Cabin Lighting	34	Map Lights	15	Oil Pressure Gauge	6	Powerplant Emergency Systems
29	Stall Warning	30	Placards, Manual, Markings	15	Fuel Pressure Gauge	6	DNI
27	Seats Restraints/Latches	29	Mixture Control (Fuel Management)	14	Oil Temperature Gauge	6	Area Navigation Equipment
27	Airspeed Indicator	28	Rheostats	14	Detents	5	Master Switch
27	Heater/Defroster	27	Boost Pump	13	Vacuum	5	Flight Instruments (Emergency)
26	Elevator Trim	27	Fuel Warning System	13	Transponder	5	Exterior Lights
26	Propeller Control	26	Cockpit Noise	13	Marker Beacons	4	Engine Instruments (Emergency)
26	Altimeter	26	Cylinder Head Temperature	13	Speaker (Headphones)	4	DNI
24	ILS-LOC-GS Display	24	Landing Gear Warning System	13	Electrical Indicators	4	Electrical Systems
24	VHF Tuning Head	24	Cabin Ventilation (CO)	13	Light Selector Switches	3	Warning Lights
23	Electrical Switches	24	Control Locks	12	EGT Gauge	2	Elevator Control
22	Manifold Pressure Gauge	21	Audio Panels	12	Fuel Flow (Fuel Management)	2	Auto Coupler
22	Instrument Lights	22	Yoke	12	Clock		NAV/COPN System-Emergency
21	Windscreen Visibility	22	Directional Gyro	12	Electrical System Warnings		Electrical System-Emergency
21	Rudder Trim	21	Magneto Switch	11	Engine System Warnings	1	NAV/COPN System-Warning
21	Microphone/Jack	21	Primer	10	Autopilot	1	Outside Air Temperature (OAT) Gauge
						0	Aileron Control

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TABLE A-3. IDENTIFICATION OF NINE COCKPIT AREAS REQUIRING STANDARDIZATION

	Number of Pilot Comments		Number of Pilot Comments
1. Fuel Management		4. Doors (Latching and Locking Mechanisms)	59
A. Fuel Selectors	59	Logic of Operation	38
Accessibility	39	Adequacy	34
Location	35	Confusion Factor (Uncertainty)	32
Logic of Operation	29	5. Seats/Berths (Restrictions)	47
Shape	9	Adequacy (Protection)	47
Detonic Adequacy	9	Logic of Operation	44
Readability (Markings)	6	Location	44
Visibility	3	6. Seats-Latches	47
3. Fuel Quantity Indicators	51	Adequacy	44
Warning (Low Fuel Warning)	34	Logic of Operation	42
Accuracy	33	7. Power Plant Instruments	52
Location	25	A. Manifold Pressure, RPM, Fuel Flow	
Readability (Markings)	23	Arrangement	52
Visibility	11	Location	42
2. Powerplant Controls		8. Cabin Instrument Lighting	70
A. Throttle, Propeller, Mixture, Carburetor	53	Adequacy	50
Heat		Location	42
Arrangement	53	9. Circuit Protective Devices	50
Location	53	Ease of Operation	50
Shape	42	Accessibility	48
Color Coding	39	Visibility	48
Confusion Factor	35	Color Coding	32
Logic of Operation	24	Readability	30
3. Flight Instruments			18
A. Airspeed, Altimeter, Attitude, Directional	47		
Gyros			
Arrangement	47		
Location	47		
Design (Altimeter)	41		
Markings (Airspeed)	41		



APPENDIX A-4. SMALL GENERAL AVIATION ACCIDENTS/FATALITIES OCCURRING IN THE UNITED STATES AND ITS TERRITORIES AND POSSESSIONS 1964-1972

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## A Long-Term Investment

Old airplanes never die, they just . . . they just don't, that's all. Excepting an ugly, and fortunately rare, calamity, airplanes will outlive almost anything mechanical that one is likely to own.

This comforting word comes not from the people who make airplanes, but rather through those who regulate them—the FAA. It seems the aviation agency wanted to know more about the life cycle of little airplanes and commissioned a private company to find out. The findings, published as "A Study of Attrition in the Domestic General Aviation Fleet" are, upon reflection, a tribute to the way little airplanes are built, maintained and flown.

To wit:

" . . . a new, all-metal, four-place single-engine land aircraft, properly maintained and well-hangared, and used a careful 200 hours a year could last forever. In any case, given a  $\frac{3}{4}\%$  destruction rate, its half life is . . . 92 years, not a particularly propitious outlook for an industry in an economy based on planned obsolescence.

"A million dollars worth of public liability aviation insurance can be bought for \$150 a year; hull insurance ranges in premium from 1.5% to 6% of the value of the hull. These rates suggest that it is cheaper to insure an aircraft than an automobile which implies in turn that not many aircraft are involved in accidents."

While these results were complimentary, the study's purpose, as already stated, was to better define the general aviation aircraft population and life pattern. The research results pretty much confirm what pilots have long known regarding who buys airplanes, but revealed some statistical surprises, too.

Of the new single-engine airplanes built each year, the study said 25% are sold for instruction, 17% are bought by businessmen, 20% go for executive, crop dusting, air taxi and industrial rental customers and another 20% are purchased for personal transportation.

However, the study noted that by the time these planes are 10 years old, only 5% are used for instruction while those used for personal transportation climbs to 50% of the fleet and business use climbs to 25%. By this time too, about 10% of the original fleet has disappeared from the registration rolls.

At the end of the next decade, personal and business use account for 80% of the aircraft owned and the original fleet has been reduced to 72% of its original size.

The fleet will then continue to diminish with the years through accidents, scrapage or retirement, but it probably won't disappear altogether. Of the 32,000 airplanes built in 1946—30 years ago—some 10,000 of them are still flying.

The usage pattern for multi-engine aircraft is, as expected, different from that of the single-engine fleet. Seventy percent of the new multis are purchased for business use and air taxis account for 15% of the crop. As time passes, personal use of the used multis grows.

All told, the report said, "Eighty percent of the aircraft ever built are still out there." It noted that each year's crop of aircraft decreases by 3% or less annually and that these departures are "an essentially random function of age, chance of destructive accident, retirement or scrapage."

The worst year for any aircraft crop seems to be its 18th. For, the study observed, "the closer they get to age 18, the more likely they are to disappear into the parts bin of a successful fixed-base operator, as a down payment on a new (but essentially identical) model, or perhaps one that has been in a training or rental fleet for a year or so."

If a plane should survive its 18th birthday, the statisticians say it will likely live to be a very ripe old age. "Older aircraft," the report explained, "are kept and maintained and occasionally flown as aesthetic possessions."

One curious fact uncovered by the researchers is that since 1960, aircraft have been progressively more long-lived. Why? "They are more expensive," the report concludes, "hence better maintained. More and more aircraft are hangared each year further increasing their life expectancy."

"It is possible that by 1993," the report continues, "the attrition rate by age of aircraft will be essentially flat for 30 years, at an annual rate of .5% or 1%."

Perhaps mountains have a slightly better rate of attrition, but not much else.

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JANUARY 1970 - JUNE 1972

## Pilot's Total Time in Model

## Brief Description of Accident

9128.0	Flight instructor placed mixture control to cut off to show student glide ratio of aircraft. Engine would not restart.
223.2	Pilot stated he pulled mixture control in lieu of carburetor heat. Could not get engine restarted.
11.0	Student pulled mixture control to off when he intended to apply carburetor heat.
85.0	Engine quit from fuel starvation with full rich mixture being used at 2,500 foot and cruising.
631.0	Flight instructor pulled mixture control to simulate emergency landing. Engine would not restart.
596.0	Pilot inadvertently pulled mixture control instead of applying carburetor heat.
273.0	Pilot pulled mixture to idle cut off instead of pulling on carburetor heat on base leg.
69.0	Carburetor heat control found in cold position and mixture control in full lean.
203.1	Pilot pulled mixture control instead of propeller control. Pilot had logged only 1.2 hrs. in this model in last 90 days.
93.0	Pilot made take off with full rich mixture with density altitude of 7,730 feet then applied carburetor heat when engine "spattered" causing further loss of power.
387.0	Pilot applied full carburetor heat and full rich mixture at low power resulting in "loading" engine with excessive rich mixture.
33	Power loss on take off due to pulling mixture control in lieu of propeller control.
24	Power loss during approach to land. Pilot pulled mixture control thinking she was actuating manual flaps control. Aircraft equipped with electrical flaps with switch close to mixture.
19	Pilot took off with mixture leaned out due to high density altitude. Power loss on take off, pilot applied full rich mixture as taught by instructor.
5	Pilot believed to have pulled mixture control on approach in lieu of carburetor heat. Student was more familiar with the PA 28-140 aircraft. RPM dropped from 2400 to 700 when he pulled what he thought was carburetor heat.
56	Engine quit on downwind leg for landing. Pilot believed to have inadvertently pulled the mixture control in lieu of carburetor heat.
28	Attempted a take off after precautionary landing off airport with mixture control partially in lean position. Engine quit at 4 feet.
64	Student pilot on simulated engine out with fuel selector off, used mixture control as a "choke", pulling mixture out.
774	Instructor pulled mixture control for simulated emergency and engine would not restart.
39	Student inadvertently pulled mixture control in lieu of carburetor heat.
249	Pulled mixture control to simulate engine failure and engine would not respond when mixture pushed in due to low altitude.
10	Power loss on approach. Found mixture control partially in shutoff position.
175	Instructor pulled mixture control to simulate engine failure. Engine did not respond when control was placed in "rich."
35	Engine lost power on approach due to mixture in full rich at a density altitude of 5,330 feet in Idaho.
24	Pilot inadvertently pulled mixture out sometime during landing approach.
827	Pilot believed to have leaned out mixture instead of reducing propeller due to distraction on take off (floats).
682	Both mixture controls inadvertently retarded after take off with double power failure.
120.0	Pilot inadvertently pulled the mixture control rather than carburetor heat on descent.
26.0	Student pilot pulled mixture control rather than carburetor heat.
1169.1	Flight instructor pulled mixture control to simulate emergency landing after take off. Engine would not respond to throttle.
237.7	During forced landing simulation flight instructor pulled mixture control to full lean.
9.7	On second landing student pulled mixture control to off instead of applying carburetor heat.
937.0	Flight instructor moved mixture control to off position to simulate engine failure. Could not get engine restarted. Battery and alternator both found bad.
First Flight	Engine lost power on take off for reasons unknown. First flight in type. Pilot believed to have pulled mixture control in lieu of propeller pitch control. Inspectors observation included reference to identical shape of mixture and propeller controls with only distinguishing point being color.
Unknown	Fatal accident - both engines quit after low pass over field. A pilot associate stated pilot had to be constantly reminded to move propeller and mixture controls for a "go-around."
434.1	Flight instructor pulled mixture control to cut off to simulate engine failure at 800 feet.
268.0	Pilot failed to lean mixture while flying at 8,000 feet and fuel exhaustion resulted.





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## AEROSPACE RECOMMENDED PRACTICE

ARP 1166

Issued 6-15-70  
Revised

### INSTRUMENT PANEL ARRANGEMENT FOR FIXED WING AIRCRAFT UNDER 12,500 LB

#### 1. INTRODUCTION

Instrument panel arrangements have varied greatly between different models of aircraft. This has been the cause of some pilots experiencing difficulty in moving from one model aircraft to another. To efficiently perform either VFR or IFR tasks the pilot frequently has been faced with relearning the locations of the flight instruments, radios, navigation displays, switches, and controls.

To make transition easier and help eliminate pilot confusion and possible mismanagement of the airplane which could contribute to causing an accident, it is deemed desirable to improve the commonality between aircraft instrument panel arrangements, switches, and controls.

As a first step to achieving commonality this ARP is directed at placement of the basic six flight instruments and the primary navigation instruments.

#### 2. PURPOSE

This recommended practice sets forth the flight instrument panel layout as recommended by SAE Committee A-25C, Cockpit/Cabin Standardization - General Aviation Aircraft.

#### 3. SCOPE

- 3.1 The recommendations cover the arrangement of flight instruments and navigation indicators in fixed wing aircraft under 12,500 pounds.
- 3.2 The arrangements are applicable to the circular dial instruments in use at the date of issue of this ARP. It is not intended to restrict future design or display concepts or to anticipate vertical tapes, integrated displays or other new developments.
- 3.3 The recommended panel arrangement may be modified to enhance the performance of particular missions or to accommodate special capabilities of the airplane and/or instrumentation.

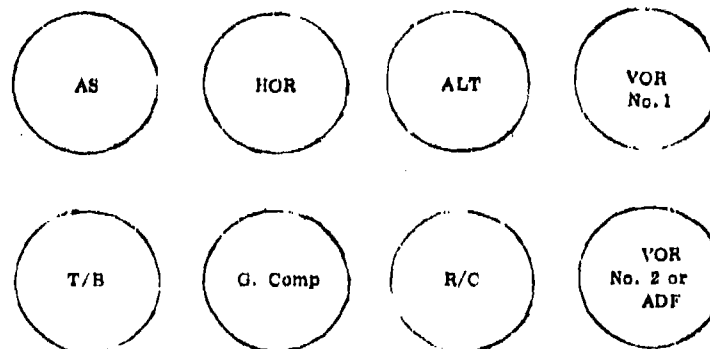
#### 4. INSTRUMENT ARRANGEMENT

- 4.1 Figure 1 shows the general relationship of the flight and navigation indicators for one pilot aircraft or the Captain's position when two pilot position instrument panels are used.
- 4.2 When two instrument panels are used for two pilot aircraft the flight instruments for the copilot should use the same arrangement as the Captain's except that the VOR No. 1 and VOR No. 2 may be disregarded.
- 4.3 The No. 2 VOR position is the preferred position for the second VOR indicator. If only one VOR is used or if another navigation instrument is used nearly equally with the VOR, that indicator may be placed in the No. 2 VOR position.
- 4.4 An Instrument Landing System glide slope cross pointer, when used, should be incorporated into the VOR No. 1 position.

## 5. INSTRUMENT PANEL LOCATION

- 5.1 The gyro horizon or instrument that most effectively indicates attitude should be as near as possible to the top most position and as near as possible to the center of the pilot's position.
- 5.2 Other indicators should be located in the general position shown in Figure 1. It is not intended that they be placed in rigid horizontal and vertical lines (although it is preferred). The indicators should be in uniformly spaced groupings in front of the pilot position.

PREPARED BY  
SAE COMMITTEE A-23,  
COCKPIT/CABIN STANDARDIZATION-GENERAL AVIATION AIRCRAFT



AS	Airspeed Indicator
HOR	Gyro Horizon Indicator
ALT	Pressure Altimeter
T/B	Turn and Bank (Slip) Indicator
G. Comp.	Gyro Compass
R/C	Rate of Climb Indicator
VOR	Course Deviation Indicator and Omni Bearing Selector

FIGURE 1

**APPENDIX B**

**AEROSPACE RECOMMENDED PRACTICE: GENERAL AVIATION SEAT DESIGN**

PROPOSED  
SAE ARP 1318  
AEROSPACE RECOMMENDED PRACTICE  
GENERAL AVIATION SEAT DESIGN

1. PURPOSE

The purpose of this ARP is to provide design criteria for pilot and passenger seats for general aviation aircraft. It includes recommendations for features involving function and utility as well as for minimum strength and energy absorption capabilities.

In the preparation of this recommended practice, consideration was given to the requirements of the Federal Aviation Regulations, the results of numerous accident investigations and research programs and the recommendations of aircraft operators and manufacturers.

2. SCOPE

The pilot/passenger seat is the basic link between the occupant and the primary structure of the aircraft. It is essential that the support and tie-down functions be accomplished in a manner that will provide maximum practical safety and security during all normal conditions of flight, emergency flight maneuvers, crash landings and survivable type accidents. These basic functions shall be given major consideration as compared to other factors such as comfort or appearance.

This ARP is intended for application to aircraft approved under Part 23 of the Federal Aviation Regulations. Although most general aviation aircraft in this category are approved for single pilot operation, those recommendations noted as applying specifically to pilot seats will be understood to apply to any seats for which the occupant has access to the airplane flight controls.

In the design areas for which they apply, the Federal Aviation Regulations should be considered minimum requirements.

3. DEFINITIONS

3.1 Seat Assembly - One complete seat unit, whether for single

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or multiple occupancy. The seat assembly may include but not be limited to the seat structure, cushions, trim panels, arm rests, dress covers, ashtrays, headrests and accessory pockets or shelves as applicable. It does not implicitly include seat belts, shoulder harnesses, seat tracks or other equipment normally attached to the primary structure of the aircraft.

3.2 Seat Primary Structure - That portion of the seat structure which provides the support, restraint and energy absorption link between the occupant and the aircraft primary structure.

3.3 Seat Secondary Structure - That portion of the seat structure intended to meet comfort, utility or appearance requirements.

3.4 Seat Ultimate Static Load - The highest load to which the seat may be subjected for a minimum of three (3) seconds without failure.

3.5 Seat Ultimate Dynamic Load - The highest load to which the seat may be subjected under conditions of dynamic arrest without failure or loss of restraint function.

3.6 Standard Occupant Weight - Static and dynamic seat loads shall be based on a standard occupant weight of 170 pounds (acrobatic 190 pounds).

3.7 Neutral Seat Reference Point - The intersection of a line tangent to the surface of the seat bottom cushion and a line through the seat back cushion representative of a back tangent line, under a no-load condition.

3.8 Seat-Back Breakover - The design feature which permits the seat-back to fold forward from the normal upright position for purposes of passenger access or seat installation, removal or storage.

#### 4. RECOMMENDATIONS

4.1 Dimensions - The recommended ranges for seat dimensions are given in Figure 1. Illustrations are for dimensional purposes only and are not intended to fix the actual shape of the seat. It is understood that all dimensions influenced by passenger weight (i.e., cushion deflection) are to be measured under 1 g static loading with an occupant of standard weight.

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- 4.2 Adjustment - Adjustable pilot seats are recommended in order to insure that occupants of different sizes and weights can perform their work in the most efficient and comfortable manner. When such adjustable seats are provided, the following adjustment ranges are recommended.
- 4.2.1 Vertical Adjustment - Where practical, the pilot seats should be adjustable vertically through a range of at least four (4) inches in increments of no greater than 1 inch throughout the entire range. The purpose of seat adjustment is to provide the optimum eye location for visibility inside and outside the cockpit and to provide comfortable and efficient access to the controls. The adjustment mechanism should incorporate a means of raising the seat freely to the maximum up position. It should be designed in such a way as to insure against inadvertent actuation to extreme positions during normal or emergency flight conditions. It is recommended that the vertical adjustment controls for the seat should be located under the left hand forward portion of the seat.
- 4.2.2 Angular Adjustment of Seat-Back - If angular adjustment is provided or if the seat-back has breakover provisions, it need not be restrained in the normal upright position against forward motion under the loads specified in Section 4 unless the shoulder restraint harness is attached to the seat back structure. If the shoulder restraint harness is attached to the seat back, then the seat back should be capable of withstanding, in any normal position, the inertia loads specified in Section 4.4.2
- 4.2.3 Fore and Aft Adjustment - Where practical, the pilot seat should be adjustable in the fore and aft direction for a distance of at least eight (8) inches in increments of not less than one (1) inch. For aircraft equipped with adjustable rudder pedals, appropriate reductions in fore and aft adjustment are acceptable so long as the relationship between the seat position(s) and the control for pitch and roll permits efficient and comfortable operation.

The fore and aft adjusting mechanism and latches should be designed in such a way as to insure against inadvertent actuation, either by the occupant or by inertial forces, to extreme positions during normal or emergency flight conditions. In the interest of standardization, the fore and aft seat actuation controls should be located under the right forward portion of the seat.

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- 4.3 Arm Rests - If arm rests are provided as part of the seat structure, they should be designed to fold in such a way as to minimize interference with entrance to or exit from the seat. Insofar as practical, arm rests should be padded or designed to reduce the likelihood of injury to the occupants in the event of a survivable crash.
- 4.4 Strength - Pilot and passenger seats should be designed to the following general and specific strength recommendations.
- 4.4.1 General
- 4.4.1.1 Failure of the seat secondary structure under crash landing conditions should not affect the strength of the seat basic structure. Consideration should be given to design features which would minimize the possibility of incapacitating or fatal injury to occupants in the event of a failure.
- 4.4.1.2 Likely deflections of floor and sidewall structure under crash landing conditions should be considered in establishing seat and seat attachment integrity.
- 4.4.1.3 Wear and tear due to normal use should be considered in designing the seat basic structure to meet the specified load conditions. Special consideration should be given to the design of adjustment mechanisms.
- 4.4.1.4 Material selection and testing should take into account possible deterioration of strength properties with time for those materials which have an effect on seat strength.
- 4.4.1.5 The seat basic structure should be suitably protected against corrosion of all types to which it may be subjected in service. The design should avoid wherever practical trapped areas where spilled liquids can accumulate and cause corrosion.
- 4.4.1.6 Seat design, construction and attachment should be such as to prevent objectable flexing of the seat under turbulent flight conditions.
- 4.4.2 Dynamic Ultimate Loads - The pilot and passenger seats and their attachment to the airframe should be designed in conjunction with the occupant restraint system, to withstand the following dynamic load factors without separation failure (refer to 4.5 on Energy Absorption).

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- 4.4.2.1 A forward load of twenty-five (25) g's applied twenty (20) degrees to either side of the longitudinal axis, an aft load of 5 g's, an upward load of 15 g's and a downward load of 15 g's. Load directions should be determined with respect to the longitudinal axis of the airplane. The pulse shapes and durations for the above loads are specified in Figure 2. Load factors should be measured at the seat tracks or on the corresponding air-frame support structure.
- 4.4.2.2 Structural compliance should be demonstrated for the most adverse combination of the loads specified in 4.4.2.1.
- 4.4.2.3 Aft-facing seats should be designed and qualified to the loads specified in 4.4.2.1. The occupant center-of-gravity to be used in the analyses of tests for aft-facing seats is given in Figure 1. When headrests are incorporated as part of the restraint system, considerations should be given to the resulting body load distribution.
- 4.4.2.4 Side-facing seats are not recommended. If used, they should be designed or located so that the occupant is restrained from lateral loadings in excess of the side loads resulting from the loadings specified in 4.4.2.1 in case of forward facing seats.
- 4.4.3. Static Loads - Since there does not appear to be a consistent relationship between static and dynamic strength of complex structures, no alternate static loads are recommended for structural substantiation of aircraft seats for use in lieu of the dynamic loads given in 4.4.2.
- 4.5 Energy Absorption - As a minimum requirement, the seat structure should be designed to deform progressively when the ultimate dynamic load is exceeded and, during deformation, to absorb as much energy as possible. For seats designed specifically to attenuate crash forces, plastic deformation of the energy absorption elements should not be considered to be a structural failure so long as the occupant support function of the seat is unimpaired.
- 4.6 Restraint Systems - The seat represents one part of the over-all occupant restraint system, which may also include the lap belt and upper torso restraint. The seat should be designed in conjunction with the other elements of the restraint system and should not interfere with their proper function. Specifically:

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- 4.6.1 Upper Torso Restraint - Seat-back height specifications of Figure 1 are based on considerations of protection, comfort and convenience. If the seat-back incorporates provision for shoulder harness attachment, the attachment position should be located above shoulder height or be designed so as to prevent the shoulder harness from imposing uncomfortable down loads under normal operating conditions. If attach point is located lower on the seat back, the seat-back should not fail under the specified dynamic conditions. (Refer to SAE ARP 1226, Occupant Restraint System (Active) for General Aviation Aircraft.)
- 4.6.2 Lap Belt - If restraint system loads are carried by the seats, the seat-to-airframe attachment strength should be equal to or greater than the dynamic load factors given in 4.4.2.
- 4.6.3 General - Seat belts and shoulder harness should be designed to be used and stored in such a way as to prevent entanglements with seat, controls or structure. Automatic storage provisions are desirable.
- 4.7 Design - The following general design recommendations are intended to improve the comfort, utility and the safety of the pilot and passenger seats.
- 4.7.1 The seat should be designed to support the occupant within the normal flight envelope and under crash conditions as defined by the minimum applied unit loadings of 4.4.2.1 and 4.4.2.3. The provision is particularly important for the design of seat pans to absorb vertical impact forces.
- 4.7.2 Seat materials should comply with the flameability requirements of Flight Standards Service Release No. 453 or later applicable documents. In addition, seat and armrest cushions and dress covers should be self-extinguishing when subjected to cigarette burns.
- 4.7.3 Materials and finishes which generate appreciable amounts of toxic gases or dense smoke when subject to flame or heat should be avoided.
- 4.7.4 The seat should be free from sharp edges or projections which could cause damage to the safety belt or clothing of the occupant or which might injure the hands of the occupant as he operates equipment within his reach.

February 28, 1975

FIGURE 1  
GENERAL AVIATION SEAT DIMENSIONS

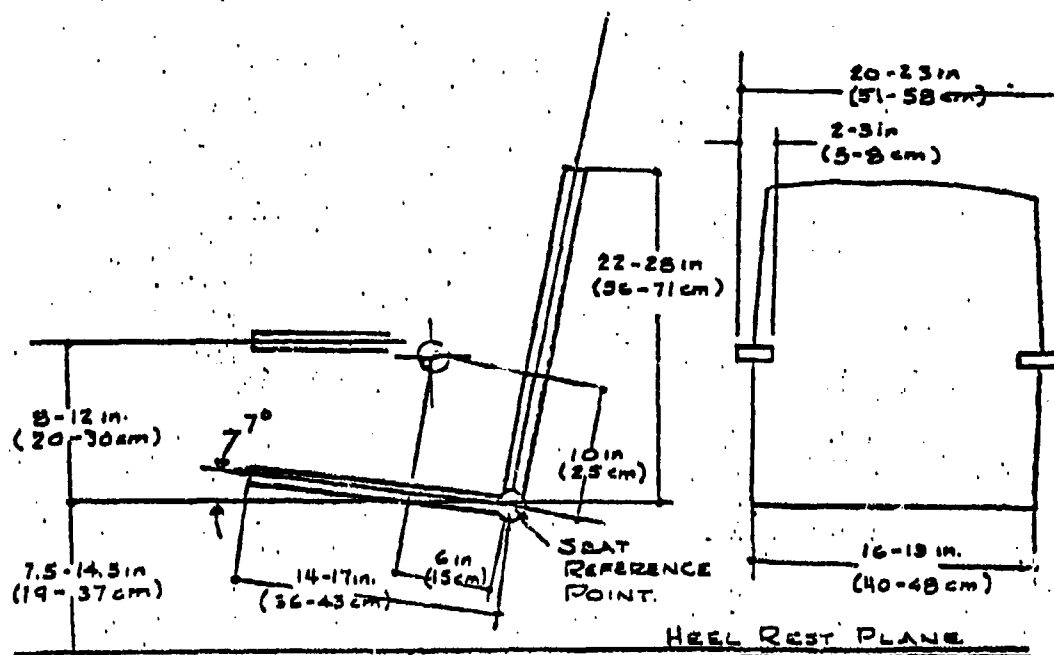
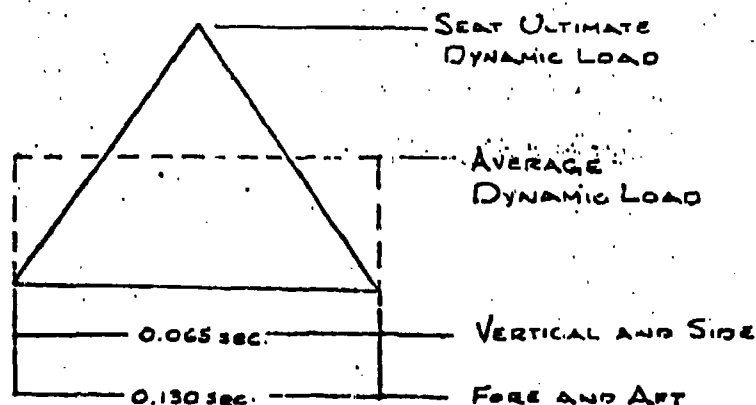


FIGURE 2  
DYNAMIC LOAD PULSE SHAPE



**APPENDIX C**

**GAMA LETTER TO FAA, JULY 26, 1976**



**General Aviation  
Manufacturers Association**

Suite 1215  
1025 Connecticut Ave., N.W.  
Washington, D. C. 20036  
(202) 296-8848

November 30, 1976

To: Mr. Richard P. Skully  
Director, Flight Standards Service  
Federal Aviation Administration  
Washington, D.C. 20591

Subject: Transmittal of Findings of GAMA's Fuel System  
Standardization Ad Hoc Committee; reference NTSB  
Recommendations A-74-35, A-74-38 and A-74-39

Background

As you know, the National Transportation Safety Board promulgated a series of safety recommendations in their 1974 report entitled "Special Study, U. S. General Aviation Accidents Involving Fuel Starvation, 1970-1972", Report Number NTSB-AAS-74-1. Recommendations A-74-35 through A-74-39 were addressed to FAA while recommendation A-74-40 was addressed to GAMA. Copies of these recommendations are enclosed (See enclosure 1). On November 19, 1974, GAMA responded to NTSB, with a copy to the FAA, indicating that GAMA would provide FAA with detailed supporting information from which to respond to NTSB regarding recommendations A-74-35, A-74-38 and A-74-39 (See enclosure 2). This letter constitutes our transmittal of that data.

NTSB Recommendation A-74-35 regarding preparation of an educational  
Advisory Circular on Fuel Management

GAMA's Safety Affairs Committee, in a cooperative venture with the Ohio State University and FAA's Accident Prevention Staff, recently completed a slide-tape show on fuel management. A copy of the completed script for this presentation entitled "Time In Your Tank", and the accompanying handout, is enclosed (See enclosure 3). We sincerely believe that this presentation will complement, in spirit, any effort the FAA may take to satisfy NTSB Recommendation A-74-35. A master copy of this slide-tape show was presented to your Accident Prevention Staff (AFS-806) on November 15, 1976.

NTSB Recommendation A-74-38 regarding fuel control standardization

Enclosure 4 contains our proposed changes to FAR 23.777 through 23.781 regarding proposed specifications to standardize powerplant, flap and landing gear controls. GAMA feels that the location, shape and color for cowl flap controls are not considered critical enough to be regulated.

NTSB Recommendation A-74-39, regarding proposed standardized terms and nomenclature for fuel selector valves and other components of aircraft fuel systems

In addition to the proposed revisions to FAR 23.777 through 23.781 GAMA proposes that the following standardized terms and nomenclature relating to various fuel system components, functions and locations, be adopted. It is GAMA's intent that this standardization be used as design information only. To do otherwise would have the effect of stifling innovation and would preclude use of the "best" configuration for a particular design. If the GAMA standards are to be considered for incorporation into the regulations, additional qualifying phraseology would be required.

GAMA member companies have agreed that the design suggestions and information presented below, relative to the standardization of nomenclature, placards, and so on, will be implemented with respect to new certification programs.

A. Fuel Selector Nomenclature

1. Fuel selector placards should include the term "Usable Capacity". In addition, usable capacity should be denoted in gallons only, as opposed to pounds or pounds and gallons.
2. The fuel selector position should be denoted by using the terms "Right", "Left", "Both", "Off" and "Aux", as required. The intent is to use any one or combination of these positions as the fuel system and aircraft design dictates. In addition to the selector position, the fuel selector placard should incorporate the name of the control, i.e., "Fuel Selector".

3. Any special conditions required for a specific airplane should also be noted on the fuel selector valve placard. This is consistent with FAR 23.1555 (c) (2) and (c) (3).

It is recommended that a new paragraph (c) (4), reading as follows, be incorporated in FAR 23.1555 in order to fully achieve the objective of this requirement:

"(4) Fuel selector valve position placards must be immediately adjacent to the indicator end of the selector."

#### B. Fuel Tank Nomenclature

In addition to fuel selector valve nomenclature, GAMA has established specific standardized definitions for fuel tank nomenclature. At present, tanks may be called main, right, left, tip, nacelle, nose, and so on. The standardized definitions established are as follows:

1. Main - Any tank used for take-off and landing. It may also be considered right or left main, depending on the method in which the tankage is controlled. Any system of tanks plumbed together with no independent control of the individual tanks should be considered as a right or left main. A typical example of this type of tankage would be an airplane in which a series of tanks were installed in the wings that were inter-connected such that the fuel flows from the outboard tank to the inboard tank and from the inboard tank to the engine through a fuel selector. If there is no individual control of the outboard or intermediate tanks, then this system of tanks is considered to be a main tank, either right or left, depending upon which wing is being considered.
2. Auxiliary tank - Defined as any tank other than a main tank that can be independently selected and that will feed an engine directly through the fuel selector. If more than one auxiliary tank is installed, they should be numbered in the primary sequence of use.

3. Transfer tank - Any tank that serves a storage or transfer function should be termed a transfer tank. Further identification of this type of tank carries the requirement that no control can be exercised over this tank other than for transfer purposes wherein fuel flows from the transfer tank into one of the mains or auxiliary tanks for subsequent delivery to the engine through a fuel selector. Typical examples of this type of tank are found in some smaller single engine aircraft with a transfer tank installed in the baggage compartment or other convenient location from which the fuel is subsequently pumped by a transfer pump into one of the main tanks for subsequent distribution through the selector valve.

C. Fuel Quantity Indicators

It is believed that the present industry nomenclature for fuel quantity indicators is adequate and no changes are recommended.

D. Fuel System Drains

Fuel system drains and their nomenclature were reviewed. It was agreed that each drain should be clearly marked and that supplemental information, as required, must identify what is being drained as well as how to operate that drain.

E. Special Requirements

GAMA's Fuel Standardization Ad Hoc Committee also reviewed certain special requirements with respect to specific conditions, on specific aircraft. Typical examples are special unusual fuel conditions, warning systems and so on. It was agreed that, by their very nature, these conditions are unique and no changes to present practices are recommended.

It is hoped that these comments will be of assistance to the FAA. If we can be of further assistance, please let us know.

Sincerely,

Original Signed By  
Stanley J. Green  
Vice President

Source: SPECIAL STUDY  
U.S. General Aviation Accidents  
involving fuel starvation  
1970-1972  
National Transportation Safety Board  
Washington, D.C. 20591  
Report Number: NTSB-AAS-74-1

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#### RECOMMENDATIONS

The National Transportation Safety Board believes that the number of U. S. General Aviation fuel starvation accidents can be substantially reduced by constructively changing the above conditions. Accordingly, the Safety Board recommends that the Federal Aviation Administration:

1. Issue an Advisory Circular, which augments the information presented in Federal Aviation Administration Advisory Circular No. 20-43B "Aircraft Fuel Control," (a) to alert general aviation pilots of the primary difficulties causing fuel starvation; and (b) to warn certificated flight instructors of the danger associated with simulation of emergency engine failure by positioning the fuel selector valve to "off" or the mixture control to "idle cutoff."  
(Recommendation A-74-35)
2. Amend 14 CFR 23.1581 so that an approved Airplane Flight Manual is required for all airplanes regardless of weight,



thereby assuring greater consistency and attention to detail than is currently available in most owner manuals for airplanes which weigh less than 6,000 pounds. (Recommendation A-74-36)

3. Promote awareness of fuel starvation problems among those individuals who are beginning careers as student pilots by:
  - a. Requiring a written test as part of student pilot flight requirements in 14 CFR 61.63, similar to that required for private pilots in 14 CFR 61.87.
  - b. Structuring written tests so that an applicant's knowledge of fuel system operating principles and factors which cause fuel starvation can be determined. (Recommendation A-74-37)
4. Amend 14 CFR 23.777 through 23.781 to include specifications for standardizing powerplant control location, visual and tactile appearance, and mode of actuation, similar to the specifications for transport category airplanes appearing in 14 CFR 25.777 through 25.781. (Recommendation A-74-38)
5. Amend 14 CFR 23 to include specifications for standardizing fuel selector valve handle designs, displays, and modes of operation. (Recommendation A-74-39)

In addition, the Safety Board recommends that the General Aviation Manufacturers Association (GAMA) establish industry-wide recommended design practices for fuel systems of future general aviation airplanes, and where practicable apply these same practices to existing models through system modifications. Application of these practices to all existing airplanes may be impossible for reasons of cost or physical constraints; however, the following practices could be applied to the design of future airplanes at a minimum cost: (Recommendation A-74-40)

- a. Specifications for a low fuel warning device which operates independently of the fuel gage system.
- b. Specifications for a water contamination warning system.
- c. Specifications for more accurate type of fuel quantity gaging system.
- d. Specifications for multiple fuel tank vents and nonicing tank vents to minimize the possibility of vent obstruction.
- e. Simplification of the fuel system through the use of the balanced, single-tank design concept.

PROPOSED REVISIONS TO FAR 23.777 THROUGH 23.781

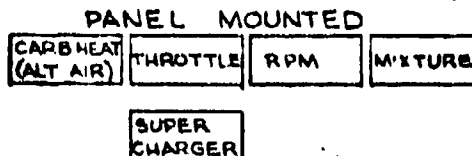
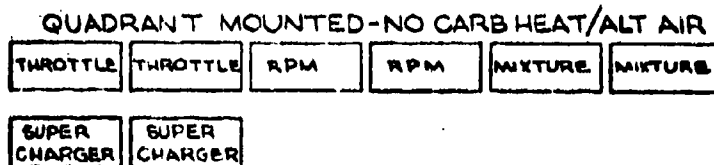
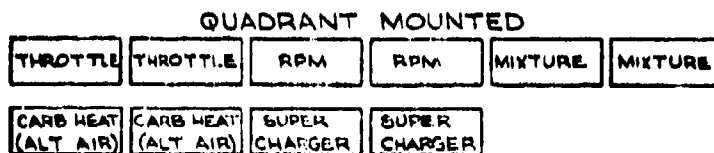
23.777 Cockpit controls

(a) Each cockpit control must be located and (except where its function is obvious) identified to provide convenient operation and to prevent confusion and inadvertent operation.

(b) The direction of movement of cockpit controls must meet the requirements of 23.779. Wherever practicable, the sense of motion involved in the operation of other controls must correspond to the sense of the effect of the operation upon the airplane or upon the part operated. Controls of a variable nature using a rotary motion must move clockwise from the off position, through an increasing range, to the full-on position.

(c) The controls must be located and arranged so that the pilot, when seated, has full and unrestricted movement of each control without interference from either his clothing or the cockpit structure.

(d) Power plant controls shall be located on a pedestal or near the centerline of the instrument panel. The location order from left to right shall be throttle, propeller and mixture control. Supplemental controls such as auxiliary air and supercharger controls shall be organized in accordance with the following layout:



(d) Cont'd

Aircraft with tandem seating or single place aircraft may utilize control locations on the left side of the cabin compartment and location order from left to right shall be throttle, propeller and mixture.

(e) Identical powerplant controls for each engine must be located to prevent confusion as to the engines they control.

(1) Conventional multi-engine powerplant controls shall be located so that the left hand control(s) operates the left engine(s) and conversely the right hand control(s) operates the right engine(s).

(2) On tandem twin engine aircraft, the left hand powerplant control must operate the front engine and the right hand powerplant control must operate the rear engine.

(f) Wing flap and auxiliary lift device controls must be located:

(1) Centrally, or to the right of the pedestal or powerplant throttle control centerline; and

(2) Far enough away from the landing gear control to avoid confusion.

(g) The landing gear control must be located to the left of the throttle centerline or pedestal centerline.

(h) Each fuel feed selector control must be located and arranged so that the pilot can see and reach it without moving any seat or primary flight control when his seat is at any position in which it can be placed. In addition, the following apply:

(1) The indication of the selected fuel valve position must be by means of a pointer and must provide positive identification of the selected position.

(2) The position indication pointer must constitute or be located on that part of the handle that is the maximum dimension of the handle measured from the center of rotation.

(h) Cont'd

(3) If the fuel valve selector handle is also a fuel shut off selector, the off position marking must be colored red. If a separate emergency shut off means is provided, it also must be colored red.

(1) Control knobs, color and shape, must be in accordance with FAR 23.781.

23.799 Motion and effect of cockpit controls

Cockpit controls must be designed so that they operate in accordance with the following movement and actuation:

(a) Aerodynamic controls:

(1) *Primary*

*Controls*  
Aileron

*Motion and effect*  
Right (clockwise) for  
right wing down.

Elevator

Rearward for nose up.

Rudder

Right pedal forward for  
nose right.

(2) *Secondary*

*Controls*  
Flaps (or auxiliary  
lift devices)

*Motion and effect*  
Forward or up for flaps up  
or auxiliary device stowed;  
rearward or down for flaps  
down or auxiliary device  
deployed.

Trim tabs (or  
equivalent)

Actuate to produce similar  
rotation of the airplane  
about an axis parallel to the  
axis of the control.

(b) Powerplant and auxiliary controls:

(1) *Powerplant*

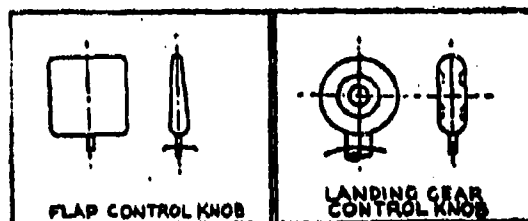
<i>Controls</i>	<i>Motion and effect</i>
Throttles/Thrust	Forward to increase forward thrust and rearward to increase rearward thrust.
Propellers	Forward to increase rpm.
Fuel condition	Forward or upward for on.
Mixture	Forward or upward for rich.
Carburetor air heat or alternate air	Forward or upward for cold. Forward or upward for low blower.
Supercharger	For turbosuper-chargers, forward, upward or clock-wise to increase pressure.

(2) *Auxiliary*

<i>Controls</i>	<i>Motion and effect</i>
Cowl flap control	Rearward or down for cowl flap open.
Fuel selector	The operating motion of the fuel valve selector handle must be to the right for right hand tanks, to the left for left hand tanks, and to the extreme left, or aft, for off. All other tank selections must be located between the left and right tank positions, except a crossfeed position on individual engine selector valves for multi-engine aircraft must be located to the extreme right or forward.
Landing gear	Down to extend.

# 23.781 Cockpit control knob shape and color

Cockpit control knobs must conform to the general shapes and color (but not necessarily to the exact sizes or specific proportions) as shown in the following figures:



QUADRANT MTD		PANEL MTD		BASIC COLOR
				BLACK
THROTTLE CONTROL KNOB				
				BLUE
RPM CONTROL KNOB				
				RED
MIXTURE CONTROL KNOB				
				GREY
CARB HEAT OR ALT AIR CONTROL KNOB				
				BLACK
SUPERCHARGER CONTROL KNOB				

**APPENDIX D**

**FUEL STARVATION ACCIDENT DATA**

# FLIGHT INSTRUCTORS' SAFETY REPORT

THE AOPA AIR SAFETY FOUNDATION, FLIGHT INSTRUCTOR DEPARTMENT 7315 WISCONSIN AVENUE/BETHESDA, MD. 20014

Volume 2 No. 2

April, 1978

## U.S. GENERAL AVIATION ACCIDENTS INVOLVING FUEL STARVATION 1970-1972 NTSB REPORT #AAS 74-1 ABBREVIATED

### INTRODUCTION

This study was initiated by NTSB as a result of the findings of a previous National Transportation Safety Board study titled "Accidents Involving Engine Failure/Malfunction U.S. General Aviation 1965-1968," which revealed that 19.3 percent of 4,310 engine failure accidents had been caused by fuel starvation.

The objectives of this study are: To identify the most frequent causes of fuel starvation accidents; to examine the factors involved in those causes, and to propose remedial action to reduce the number of fuel starvation accidents.

### BASIS FOR STATISTICAL ANALYSIS

The scope of this study was limited to the most frequently occurring causes so that causal areas and associated factors could be researched thoroughly. The study concentrated on airplane makes and models most susceptible to fuel starvation accidents and, for comparison, those least susceptible.

For purposes of this study, fuel starvation is defined as the interruption, reduction, or complete termination of fuel flow to the engine, although ample fuel for normal operation remains aboard the aircraft.

Of the 99 airplane makes and models involved in fuel starvation accidents from 1970 through 1972, 70 makes and models accounted for only 27 percent of the reported accidents. Therefore, to save time, those makes and models which accounted for less than 0.813 percent of the base period fuel starvation accidents were not analyzed further. Accordingly, 29 makes and models were selected for statistical evaluation.

Of the 29 makes and models analyzed, (which accounted for 63% of the accidents) 15 were involved in an average number of fuel starvation accidents in 1970 through 1971, nine were involved in a higher (H or VH) number of fuel starvation accidents than expected, while three were involved in a lower (L or VL) number than expected. Two airplanes could not be analyzed because of insufficient flight hour data.

### CAUSES OF FUEL STARVATION ACCIDENTS

From 1970 through 1972, there were 126 fuel starvation accidents in which high involvement group airplanes were involved. The most frequently cited causes of fuel starvation for this group are: Exhaustion of fuel from the tank in use while ample fuel for continued operation remained on the aircraft; nonadherence to airplane operating limitations imposed by airworthiness directives; mechanical malfunctions which resulted in fuel starvation; incorrect positioning of the fuel selector valve, and contamination of the fuel system.

From 1970 through 1972, there were 66 fuel starvation accidents in which low involvement group airplanes were involved. The most frequently cited causes for fuel starvation accidents for this group are: Contamination of the fuel system, improper use of powerplant controls; instructional simulation of in flight power loss, incorrect positioning of the fuel selector valve and mechanical malfunctions which resulted in fuel starvation.

Two of the five most frequently cited causes for the high and low involvement groups appeared in about the same percentage for each group. These causes were: Mechanical malfunctions and incorrect positioning of the fuel selector valve.

A review revealed that most instances of incorrect fuel selector valve positioning resulted because the pilot was confused about the mode of valve operation, valve handle design, or fuel selector tank display.

### CAUSE/FACTOR DATA FUEL STARVATION ACCIDENTS, 1970-1972 High and Very High Involvement Group Airplane

Make/Model	WFFSY	ED	MPFSY	MTFC	COMT	LT	K	LAD	MEF	DMOD	UNK
Callan A9	2										
A9A	1										
A9B	7										
Boech 30	2	1									
30A	2	2									
B38	1										
C38	1										
D38	1										
H38	1										
J38	1										
K38	1										
M38	1										
P38	1										
B38	1										
V 38A	1										
V 38B	1										
38 33	1										
35 D33	1										
Conversion E 50	1										
V 35	1										
Boech 45											
45A55											
45B55											
45C55											
Boeing A 74N1											
Navion A											
Bellanca 17 80											
17 80A											
Piper PA 12											
PA 12J											
135											
150											
108											
125											
160											
PA 24											
180											
250											
260											
400											

1. Failure improper use of fuel selector valve (off) tanks in use exhausted (fuel dry) in flight, while ample fuel remained aboard.

2. Fuel selector valve (off) tanks in use exhausted (fuel dry) in flight, while ample fuel remained aboard.

3. Fuel selector valve (off) tanks in use exhausted (fuel dry) in flight, while ample fuel remained aboard.

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Many pilots positioned fuel selector valve handles to the "off" position or to an empty tank, while under the impression that they had selected a tank which contained fuel. All these causes involve operational procedures and techniques employed by pilots.

Two of the 10 causes cited for high involvement group airplanes accounted for 52 percent of the fuel starvation accidents. These causes were: Exhaustion of fuel from a tank in use while ample fuel for continued operation remained aboard the aircraft, and noncompliance with operating limitations imposed by airworthiness directives. For the low involvement group airplanes, three of nine cited causes accounted for 63 percent of the fuel starvation accidents. These causes were: Fuel system contamination, improper use of powerplant controls, and

THE DATES OF THE FLIGHT INSTRUCTOR REFRESHER COURSE AT CHAMPAIGN, ILLINOIS, HAVE BEEN CHANGED TO AUGUST 14 16, 1978 (Saturday, Sunday and Monday).



instructional simulation of in-flight power loss. The main reason stated in accident reports for the problems peculiar to each group were:

#### High Group

For exhaustion of fuel from a tank in use:

- (1) allowing fuel to become exhausted was normal procedure recommended in owner manuals of some aircraft;
- (2) pilots forgot to switch tanks before exhaustion of fuel from the tank in use;
- (3) engine was not restarted in sufficient time to prevent an accident.

For lack of compliance with fuel system operational limitations imposed on certain aircraft by airworthiness directive:

- (1) pilots did not fully comprehend the AD requirements;
- (2) they simply ignored them.

#### Low Group

For improper use of powerplant controls: The pilot used the mixture control when he intended to apply carburetor heat.

For fuel system contamination:

- (1) water was not properly drained from the fuel system;
- (2) foreign objects obstructed fuel tank vent lines.

For instructional simulation of in-flight power loss: The instructor attempted a power loss simulation, as a test for a student pilot, by turning the selector valve "off", or placing the mixture control in the "idle cutoff" position (three of these simulated emergencies were initiated at less than 1,200 feet above the ground).

Only one multi-engine general aviation airplane, the Beech 95, was involved in a more-than-average number of fuel starvation accidents during the 1970-1972 period. Four of the five fuel starvation accidents in which this multi-engine airplane was involved were attributed directly to a violation of recommended operating limitations imposed by an airworthiness directive. The directive required takeoff on main tanks only and prohibited turning takeoffs or takeoffs immediately following fast taxi turns.

### **POTENTIAL SOURCES OF OPERATIONAL DIFFICULTIES**

Most fuel starvation accidents reviewed involved operational problems which indicated a need to evaluate certain influential factors associated with operational techniques. Accident case research indicated that operational techniques involving such factors as awareness and understanding of proper fuel management could be influenced significantly by information provided in airplane owner manuals and by fuel system components which may induce operational errors.

#### **Fuel Management Instructions**

A review of the fuel management information for selected airplanes indicated that the older owners manuals contained less fuel management information than more recent manuals. Although running one tank dry before switching to another tank was once an accepted practice, most manufacturers no longer recommend it. In fact, the most recently published Beech manuals consider engine failure caused by insufficient fuel an emergency and list in-flight engine start procedure as an emergency procedure.

#### **Fuel Draining Instructions**

Fuel system contamination was responsible for 26 percent of low-involvement group fuel starvation accidents and 9 percent of high-involvement group fuel starvation accidents. Water in the fuel and foreign object obstruction of fuel tank vents were the primary contamination difficulties which caused an investigation of fuel system draining procedures and pre-flight checklist procedures in owner manuals of high- and low-involvement group airplanes.

Obviously, some owner manuals for airplanes in both the high- and low-involvement groups were more explicit about fuel system draining procedures than others. Procedures insufficiently detailed could result in incomplete draining operations; for example, instructing a pilot only to open a quick drain sump in a fuel strainer or selector to purge water or sediment from the system may not alert the operator to the absolute necessity of purging all fuel lines and tank sumps in the proper sequence to assure the elimination of all contaminants.

#### **Error-Inducing Elements of the Fuel System**

The high-involvement group airplanes experienced difficulty with fuel exhaustion from a tank in use while ample fuel for normal operation remained onboard. Both high- and low-involvement groups experienced accidents which resulted from mispositioning the fuel

selector valve. Improper use of engine controls and fuel contamination were troublesome for pilots of low-involvement group airplanes. As a result of these findings, tank switching requirements, fuel system purging features, and powerplant control configuration were researched to find possible error-inducing sources within the fuel system.

#### **Fuel Selector Valves**

Virtually all tank switching problems involved the fuel selector valve. Although fuel selector mispositioning was an operational error, the degree to which selector handle design, selector orientation, location, and tank display influenced selector operation was of interest. The extent to which pilot error was induced by fuel selector design was documented in NTSB Report PB 175629, "Aircraft Design Induced Pilot Error," dated July 1967. Accident reports from 1970 through 1972 period indicate that selector design still confuses operators and induces tank selection errors.

The influence of tank switching requirements as a factor in fuel starvation accidents was illustrated by the Cessna 150 accident statistics. This airplane is equipped with a two-position (ON or OFF) fuel shutoff valve, instead of a multi-position fuel selector valve so tank selection is not necessary. Although the Cessna 150 had accumulated the largest airplane hour total in 1970 through 1972, it was involved in only 38 fuel starvation accidents in 1970 through 1972. Of these only one was caused by improper positioning of the fuel valve and one by fuel exhaustion.

#### **Powerplant Controls**

The use of an incorrect engine control accounted for 22 percent of all causes cited for low-involvement group fuel starvation accidents from 1970 through 1972. Only 2 percent of the high-involvement group's causes involved incorrect use of engine controls. Inadvertent use of the mixture control, when the pilot thought he was using the carburetor heat control, accounted for most of the causes cited for low-involvement group airplanes. The placement of the engine controls for low-involvement group airplanes has varied through the years. Early models were configured so that carburetor heat, throttle, and mixture controls were juxtaposed horizontally with little variation in knob shape, size, or color between the carburetor heat and mixture controls. Control knob size, shape, and color has been varied in recent models of these airplanes. From 1970 through 1972, the Beech 35 was not involved in a starvation accident caused by improper use of engine controls. The mixture control in the Beech 35 is isolated sufficiently from other powerplant controls so that pilots did not confuse them. Proximity of controls of a similar size and shape, which perform entirely different functions, was considered as a possible source of error inducement in accidents which involved the use of the wrong control. To minimize incorrect control operation, the Federal Aviation Regulations (14 CFR 25.777 through 25.781) specify standards of powerplant control location, knob shape and mode of actuation for transport category airplanes, however, except for throttle actuation regulations, similar powerplant control specifications do not exist for normal, utility, and acrobatic category airplanes which comprise the largest segment of the general aviation fleet.

#### **Manufacturers' Viewpoint Regarding Error Inducement**

Three major general aviation airplane manufacturers, who deal with multi-faceted fuel system design problems, were invited to discuss the elements of the fuel system which are regarded as potential sources of operational problems. The difficulties associated with tank selection requirements, fuel exhaustion from a tank in use, fuel contamination, and adequacy of owner manual procedures were discussed.

#### **Tank Selection Requirements**

The manufacturers agreed that a balanced single tank fuel system (where interconnected cells act as a single tank to supply fuel to the engine through a shutoff valve instead of through a fuel selector valve) would simplify fuel management procedures.

#### **Exhaustion of a Tank**

Manufacturers were greatly concerned about the apparent lack of attention to fuel supply which is apparent from the number of accidents resulting from the exhaustion of a tank while ample fuel remained on board the aircraft.

#### **Pilot Awareness**

While manufacturers expressed the general opinion that fuel system design improvements and operational procedure improvements could diminish fuel starvation problems, they stressed the importance of pilot awareness with regard to proper fuel system maintenance and operation and the fundamental sources of fuel starvation.

### **CONCLUSIONS**

The message which evolves from the ~~exam~~ of fuel starvation accidents is very clear: thorough preflight fuel system inspection and

draining, complete familiarity with powerplant control configuration and operation, and attentiveness to fuel supply are all absolutely essential to safe airplane operation.

Whereas nearly 87 percent of the fuel starvation accidents in this study were attributed to operational problems, these problems are not independent of the factors which influenced or caused them. Therefore, remedial action must be directed at the primary factors which influence fuel system operation. These factors are as follows:

#### Design-Associated Factors

Owner manuals which often lack detailed information on fuel management and fuel system purging operations.

Fuel systems which require tank switching in order to manage the fuel supply properly.

Fuel selector valves with handle design, mode of operation, or tank display which may be conducive to mispositioning.

Placement of engine controls and similarity of appearance which may be conducive to improper use.

#### Pilot-Associated Factors

Instructional techniques for emergency simulation by deliberate fuel starvation at low altitude.

Lack of knowledge or concern for good fuel management procedures and techniques, including the need for thorough pre-flight fuel system inspection and purging.